



# **Medial compartment erosion of the canine elbow joint:**

**Description, diagnosis and prevention.**

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Dissertation submitted in fulfillment of the requirements for the degree of Doctor in Veterinary Sciences (PhD), Faculty of Veterinary Medicine, Ghent University

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*'There are no secrets to success.*

*It is the result of preparation, hard work, and learning from failure.'*

-Colin Powell



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## **LIST OF ABBREVIATIONS**

3D	Three-dimensional
BODPUO	Bi-Oblique dynamic proximal ulnar osteotomy
CT	Computed tomography
CUE	Canine unicompartmental elbow
DICOM	Digital imaging and communications in medicine
ERHO	External rotational humeral osteotomy
IEWG	International Elbow Working Group
IV	Intravenous
kV	kiloVoltage
LHC	Lateral part of the humeral condyle
mA	miliAmpère
MCD	Medial coronoid disease
MCE	Medial compartment erosion
MCP	Medial coronoid process
mg/kg	Milligram per kilogram
MHC	Medial part of the humeral condyle
mm	Millimeter
MRI	Magnetic resonance imaging
NA	Not available
NSAID	Non-steroidal anti-inflammatory drug
OCD	Osteochondritis dissecans
PAUL	Proximal abduction ulnar osteotomy
Po	Postoperative
PURO	Proximal ulnar rotational osteotomy
PVF	Peak vertical force
R	Radius
SC	Subcutaneous
SHO	Sliding humeral osteotomy
U	Ulna
UTN	Ulnar trochlear notch
WL	Window length
WW	Window width





## **PREFACE**



## **PREFACE**

Elbow dysplasia is a frequent cause of thoracic limb lameness in medium and large breed dogs. The elbow dysplasia complex includes disease of the medial coronoid process, osteochondritis dissecans, ununited anconeal process and joint incongruity. The primary lesions are often combined with a varying degree of cartilage damage. In an advanced stage cartilage lesions affect the medial elbow compartment. Therefore the term ‘medial compartment erosion’ is used, referring to full-thickness cartilage loss of the medial part of the humeral condyle and the corresponding ulnar contact area. In the past this severe cartilage damage was often named ‘medial compartment disease’ or ‘medial compartment syndrome’. However, to avoid misunderstanding and interchangeable use with the term ‘medial coronoid disease’, the descriptive term ‘medial compartment erosion’ seemed more appropriate and is currently being used in literature and in this thesis.

The diagnosis of elbow dysplasia is mostly based on primary or secondary radiographic changes, often combined with computed tomography findings and/or arthroscopy. Arthroscopy is the only technique that allows an accurate evaluation of the articular cartilage surface and is thereby required to confirm the diagnosis of erosion of the medial compartment.

Several load-transferring and arthroplasty techniques have been developed to treat erosion of the medial elbow compartment. However, another approach is to improve or modify current treatment methods of medial coronoid disease to ameliorate long-term treatment results and thereby potentially prevent the development of medial compartment erosion.

In the first part of this thesis (**Section I**), the occurrence, diagnosis and available treatment options of medial compartment erosion are reviewed. The second part (**Section III**) discusses the arthroscopic, computed tomographic and radiographic findings in dogs with elbow lameness after the initial arthroscopic treatment of medial coronoid disease (**Chapter 1**) and in elbows with erosion of the medial compartment specifically (**Chapter 2 and 3**). Finally, the long-term results of a novel treatment approach for medial coronoid disease in juvenile dogs are reported (**Chapter 4**).



## **SECTION I**

### **GENERAL INTRODUCTION**



**EROSION OF THE MEDIAL COMPARTMENT OF THE CANINE ELBOW:**  
**OCCURRENCE, DIAGNOSIS AND CURRENTLY AVAILABLE TREATMENT**  
**OPTIONS.**





**EROSION OF THE MEDIAL COMPARTMENT OF THE CANINE ELBOW:  
OCCURRENCE, DIAGNOSIS AND CURRENTLY AVAILABLE TREATMENT  
OPTIONS.**

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## **Introduction**

Elbow dysplasia frequently causes forelimb lameness in young and adult large breed dogs (1-4). The elbow dysplasia complex includes several pathologies such as osteochondritis dissecans (OCD) of the medial part of the humeral condyle (MHC), an ununited anconeal process, joint incongruence and disease of the medial coronoid process, combined with a varying degree of cartilage damage (1, 3, 4). In a more advanced stage of medial coronoid disease, full thickness cartilage lesions in the medial elbow joint compartment develop (3, 4).

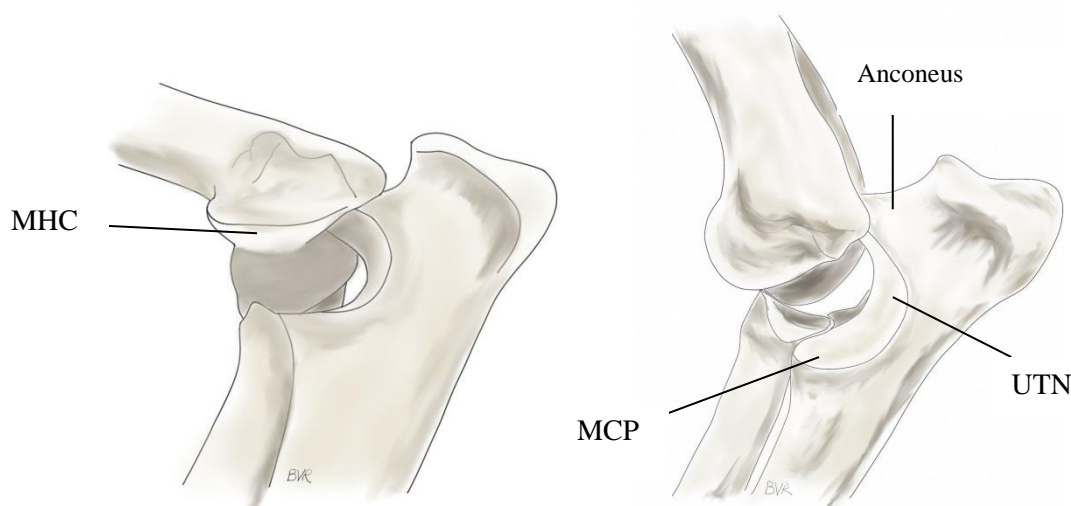
With the use of arthroscopy, the presence of cartilage lesions on the medial part of the humeral condyle (MHC) possibly caused by friction from a fragment of the opposing medial coronoid process (MCP) has been recognized as a frequent finding in advanced elbow disease. Additionally, cartilage pathology of the medial compartment in the absence of fragmentation of the medial coronoid process has also been reported since the early use of arthroscopy (1).

Recently these erosions have gained more interest, because they are diagnosed more frequently since the use of arthroscopy (3-6). It is important to diagnose these severe erosions to facilitate treatment decision-making (7-8). Demonstrating the presence of these lesions is the first challenge, because radiography and computed tomography (CT), the most commonly used techniques to diagnose elbow disorders (9), are unable to visualize cartilage lesions. However, direct inspection via arthroscopy is a reliable technique to accurately diagnose the depth and extension of the erosions (1, 10-12). The second challenge in joints with erosion of the medial compartment is the reduced ability of cartilage to heal. The regeneration capacity of cartilage is limited (13) and underlying mechanical factors may obstruct healing. Since degenerative joint diseases frequently occur in man and dogs, cartilage repair is an important current research focus. Other than general methods to treat cartilage lesions, some specific treatment methods have been designed to reduce the load within the medial compartment of the elbow joint in dogs (5, 14, 15). Moreover, several arthroplasty methods are already available (16, 17), but further modifications of these techniques are required to improve the results.

The purpose of this part of the thesis is to give a short summary on elbow dysplasia in general and a more detailed overview on the current knowledge about the occurrence, diagnosis and treatment of erosion of the medial elbow compartment.

### **Elbow anatomy and contact mechanism**

The canine elbow joint is a compound joint consisting of the humeroulnar, humeroradial and proximal radioulnar articulations. Elbow motion primarily occurs in a sagittal plane. However, due to the pivot articulation of the radioulnar joint pronation and supination of the antebrachium is also possible (18). Three distinct areas of articular contact are present in the normal elbow joint: the radius, the cranio-lateral aspect of the anconeus and the MCP (19). Earlier it was assumed that the radius was the main weight-bearing bone of the antebrachium, but a recent study illustrated that mean forces for the radial proximal articular surface were only slightly greater than for the ulna, averaging 51-52% of total forces (20). The medial compartment of the elbow joint consists of the medial coronoid process, the medial part of the humeral condyle and the medial part of the semilunar ulnar notch (Figure 1).



**Figure 1: Illustration of the anatomy of the canine elbow joint. MHC: medial part of the humeral condyle, MCP: medial coronoid process, UTN: ulnar trochlear notch.**

## **Elbow dysplasia**

The term elbow dysplasia was introduced in the mid 80's. Nowadays, elbow dysplasia is known as a complex polygenetic and multi-factorial developmental condition, mainly diagnosed in large breed dogs, such as the Labrador retriever, Rottweiler, German Shepherd and Bernese Mountain Dog (21-24). Currently, elbow dysplasia has a reported prevalence of 13.1% in Belgium (24). Several studies have examined the genetic base of elbow dysplasia. There is evidence that the different manifestations of elbow dysplasia could be inherited independently and also be inherited differently in different breeds (23). Due to the complexity of the underlying genetic inheritance and the effect of environmental factors in disease expression, it is unlikely genetic testing will be possible in the near future (23).

### ***Medial coronoid disease***

Pathology of the MCP is the most common disorder of the elbow dysplasia complex and includes fissuring and fragmentation of the MCP combined with a variable degree of cartilage and/or subchondral bone pathology (1, 3, 9). The exact cause of medial coronoid disease is unknown but several theories including joint incongruence, disturbance of the endochondral ossification, etc. have been proposed (22, 25). Dogs with medial coronoid disease most frequently present with lameness between the ages of 7 to 9 months, but it has been diagnosed at a later age and even in old dogs as well (4, 9). The diagnosis of medial coronoid disease can be easily missed on plain radiographs due to superimposition of the MCP on the radial head (Figure 2). CT and arthroscopy are often required to reach a conclusive diagnosis (3, 9, 22).

### ***Osteochondritis dissecans***

Osteochondritis dissecans (OCD) is caused by a disturbance in the process of endochondral ossification, leading to cartilage retention, and the formation of a flap (9). In OCD of the elbow joint the detached cartilage flap is localized at the MHC. Mainly juvenile dogs are affected and it is often simultaneously seen with medial coronoid disease (9, 10). OCD-lesions of the elbow joint are usually diagnosed on a 15°-oblique cranio-caudal view (Figure 2) (9, 22). However, due to the location it's not always easy to differentiate OCD lesions and kissing lesions on a radiograph (26).



**Figure 2: Radiographic examination of elbows with elbow dysplasia lesions. A) Mediolateral radiograph of an elbow with medial coronoid disease and concomitant flexor enthesopathy (thin arrows). An ill-defined and rounded shape of the medial coronoid process is visible (thick arrow). Actual fissuring or fragmentation is not visible. B) Mediolateral radiograph of an elbow with an ununited anconeal process (arrow). C) Craniocaudal radiograph of an elbow with OCD of the MHC. A radiolucent indentation is visible at the MHC (arrow).**

### ***Ununited anconeal process***

In small-breed dogs the anconeal process has no separate ossification centre, but is formed as a direct extension from the proximal ulnar growth centre. In large breeds dogs, especially German Shepherd dogs and chondrodystrophic breeds, the anconeal process has a separate ossification centre and fusion with the ulna occurs at the age of approximately 5 months (9, 22, 27). When there is no radiographic fusion at 20 weeks lameness can be caused by the ununited anconeal process. Generally affected dogs present between 2 and 9 months of age with unilateral or bilateral forelimb lameness (9, 22). In most cases a flexed mediolateral radiograph of the joint is diagnostic (Figure 2) (9).

### ***Joint incongruity***

Incongruity is a term describing malalignment of the surfaces of the joint (9, 21). Three types of elbow joint incongruity have been proposed or demonstrated: a radioulnar step, humeroulnar incongruity and radioulnar incisure incongruity (7, 23).

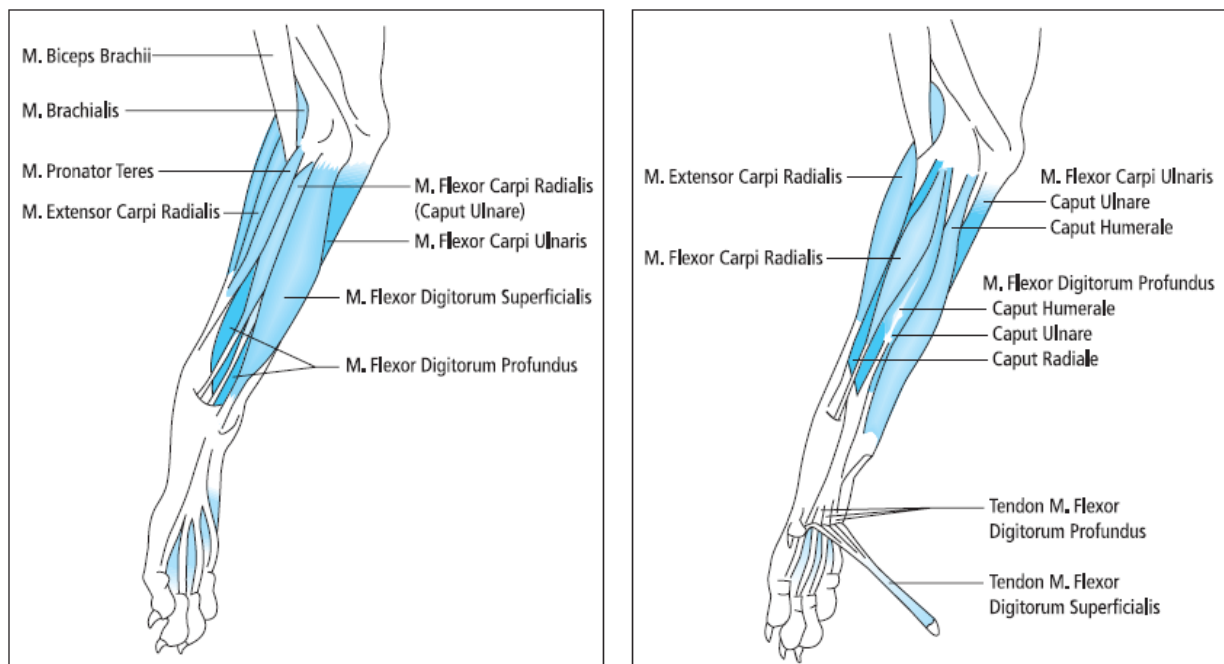
It has been hypothesized that a short radius transfers excessive weight to the MCP of the ulna, leading to fatigue microdamage of the subchondral bone (23, 26, 28). Several studies have illustrated an association between medial coronoid disease and a short radius. Nevertheless, medial coronoid disease is often diagnosed in the absence of radioulnar joint incongruity as well. A possible explanation is the presence of dynamic (instead of static) incongruity or temporary incongruity during skeletal growth (23).

Humeroulnar incongruity describes incongruity associated with the shape of the ulnar trochlear notch, possibly also leading to focally increased loading forces (7). However, a certain degree of humeroulnar incongruity is considered physiological (19).

Two potential hypothesis are proposed concerning radioulnar incisure incongruity as a possible cause for medial coronoid disease: 1) an osseus conformational radioulnar conflict at the incisure leading to crushing of the MCP against the radius, and/or 2) compression of the MCP against the radius by the eccentric pull of the biceps/brachialis muscle group (7, 23, 29).

### ***Flexor enthesopathy***

The medial epicondyle is the origin of several carpal and digital flexor muscles (Figure 3)(18). Although it is not included in the elbow dysplasia complex, changes of the medial humeral epicondyle and the attaching flexor muscles are often diagnosed concomitant with elbow dysplasia lesions (Figure 2). This pathology at the enthesis of the flexor muscles has been named ‘flexor enthesopathy’. Flexor enthesopathy can be a primary disorder or concomitant with elbow dysplasia, mostly with chronic cases of medial coronoid disease (30, 31). Primary flexor enthesopathy has recently been described as an important differential diagnosis for elbow lameness (30). It is unclear whether the concomitant presence of flexor enthesopathy has significant clinical consequences.



**Figure 3: Illustration of the superficial and deep muscles at the medial side of a right forelimb.**

### **Occurrence of erosion of the medial compartment of the canine elbow**

The medial compartment of the elbow joint consists of the medial coronoid process, the medial part of the humeral condyle and the medial part of the semilunar ulnar notch. Originally the term 'medial compartment disease' was used to describe the massive loss of cartilage in the medial part of the elbow (5). However, the term 'medial *compartment* disease' is often used interchangeably with the term 'medial *coronoid* disease', indicating fissuring/fragmentation of the medial coronoid process with or without severe cartilage damage (3, 27). Therefore the description 'erosion of the medial compartment' or 'medial compartment erosion' is being used in this paper, to avoid confusion and to set out a better specification of the pathology within the joint. Accordingly, erosion of the medial compartment refers to full thickness cartilage loss exposing the subchondral bone (modified Outerbridge grades 4-5) (table 1) of the MHC and the corresponding ulnar contact area (4, 5).

**Table 1: Modified Outerbridge classification system to score articular cartilage damage (4).**

<b>Modified Outerbridge classification</b>	<b>Description of gross cartilage findings</b>
0	Normal cartilage
1	Chondromalacia (cartilage with softening and swelling)
2	Fibrillation Superficial erosions with pitting or a 'cobblestone' appearance Lesions that do not reach subchondral bone
3	Deep ulceration that does not reach the subchondral bone
4	Full thickness cartilage loss with exposure of the subchondral bone
5	Eburnated bone

Erosion of the medial compartment of the elbow joint is a sign of severe osteoarthritis (27), since cartilage loss is one of the characteristics of osteoarthritis besides subchondral bone sclerosis, osteophyte and enthesiophyte formation and inflammation of the joint capsule (32). Joints affected by severe cartilage damage will often show these bony changes. However, in some cases clear radiographic pathology is absent, while arthroscopy demonstrates extensive erosions (4). Therefore, severe cartilage erosion of the medial compartment cannot be accurately diagnosed from just the radiographic examination.



The presence of gross cartilage damage of the MCP and the MHC in the absence of an osteochondral fragment has been reported by several authors (1, 3, 4, 33-35). Erosion of the medial compartment occurred as the only pathological finding in 6 joints in a study reporting on the pathoanatomical changes found at autopsy of 120 dogs (236 elbows). Histological examination of one of these joints revealed an irregular appearance of the superficial layer and no abnormalities of the deeper layer of the cartilage (33). This form of erosion of the medial compartment seems to occur most frequently in adult and old dogs. In a study describing the arthroscopic findings in the elbow joints of dogs of 6 years and older, 31% of the dogs showed an extensive erosion of the medial compartment of the joint without a fragmented coronoid process. The presence of only erosions in the control group of young dogs (5-18 months) in the same study was only 3 % (4). The exact cause of these cartilage lesions is unknown. Possibly, abnormal forces caused by elbow incongruity, overweight and/or high activity level may cause abnormal loading of normal or abnormal cartilage resulting in erosion of the medial compartment (3, 4). In the authors' experience, erosions of lesser severity may also affect the lateral compartment in some dogs.

Erosion of the medial compartment can occur in combination with a fragmented coronoid process and/or osteochondritis dissecans (3, 8). In those cases the erosions are considered concomitant, to indicate the simultaneous presence of the two elbow lesions without stating that one lesion is the cause or consequence of the other.

The term 'kissing lesions' is often used for cartilage erosions of the MHC in combination with a fragmented coronoid process, suggesting that the damage of the MHC is caused by friction from the coronoid lesion (7, 36). Similar cartilage lesions of the MCP were described in joints affected by osteochondritis dissecans (OCD) of the MHC (21, 26). These concomitant erosions were a common finding in studies reporting on the appearance of the joint cartilage at necropsy (21, 26, 33). One study reported deep furrows in some cases and erosions of the radial head in joints with severe osteoarthritis (33). In a study describing the arthroscopic findings in the elbow joints of 263 dogs with disease of the MCP (age 3 – 135 months), kissing lesions (modified Outerbridge grade > 0) were identified in 49% of the elbows. Modified Outerbridge grade 4 and 5 cartilage lesions of the MHC and of the MCP (= erosion of the medial compartment) were identified in 14.4 % of the elbows. A more recent theory for concomitant erosion of the medial compartment of the elbow joint states that incongruity might be the cause of cartilage loss. Fragmentation could be the early consequence of elbow

incongruity and thereafter erosion of the remaining and more resilient part of the MCP develops with subsequent erosion of the entire medial compartment (3).

Another presentation of erosion of the medial compartment has been described in a study of 35 joints of dogs with recurrent or persistent lameness after arthroscopic treatment of disease of the MCP. In this study, 60% of the joints showed extensive cartilage erosion at the second arthroscopic inspection. Many of those joints initially showed no or mild cartilage damage at the time of the first treatment (37). A similar case was described in a study on complications of elbow arthroscopy (38). To date, it is unclear whether these erosions are the consequence of the original problem or induced by the arthroscopic fragment removal which might leave a degree of instability in the joint.

### **Histopathological evaluation of cartilage damage**

The modified Outerbridge score is used to quantify cartilage pathology in terms of the depth of the lesions (4). However, cartilage can also be evaluated microscopically, using the Mankin's histological and histochemical scoring system (39). According to this system, cartilage degeneration was categorized into three stages: stage I, Mankin's score of 0-6 points, indicates mild degenerative changes, stage II, Mankin's score of 7-9 points, indicates moderate degenerative changes and stage III, Mankin's score of 10-14 points, indicates severe degenerative changes i.e. cartilage disorganization or complete cartilage loss with extensive exposure of subchondral bone (40). A moderate positive correlation has been demonstrated between the Mankin Score and the visual cartilage pathology score of the MCP in 53 canine elbows (39). In this study, elbows with an Outerbridge score 4 had a score of 10.9 +/- 0.4 by the Mankin system, equivalent to stage III cartilage degeneration (39).

## **Diagnosis**

### ***History of dogs with erosion of the medial compartment***

Since the combination of elbow dysplasia lesions and ‘kissing lesions’ is a common finding, the breeds affected by concomitant erosion of the medial compartment are similar to the breeds predisposed for elbow dysplasia (3, 4). In those studies reporting cases with erosion of the medial compartment without concomitant fragmentation of the MCP or OCD, the breed of the dogs is not mentioned. This presentation of erosion of the medial compartment seems to be more common in older dogs (> 6 years) (4) but has also been described in young dogs (< 1 year) (21). In contrast, concomitant erosion can appear both in young adult dogs (8) and in older dogs (34, 37), probably depending on the size of the lesion and the chronicity of the problem. In a study reporting erosion of the medial compartment as a finding in dogs with recurrent or persistent lameness after arthroscopic treatment of elbow dysplasia, the mean age of the dogs at second presentation was 5 years (9 months – 11 years). The average time between the first and second presentation was 2.5 years (3 months – 6 years) (37).

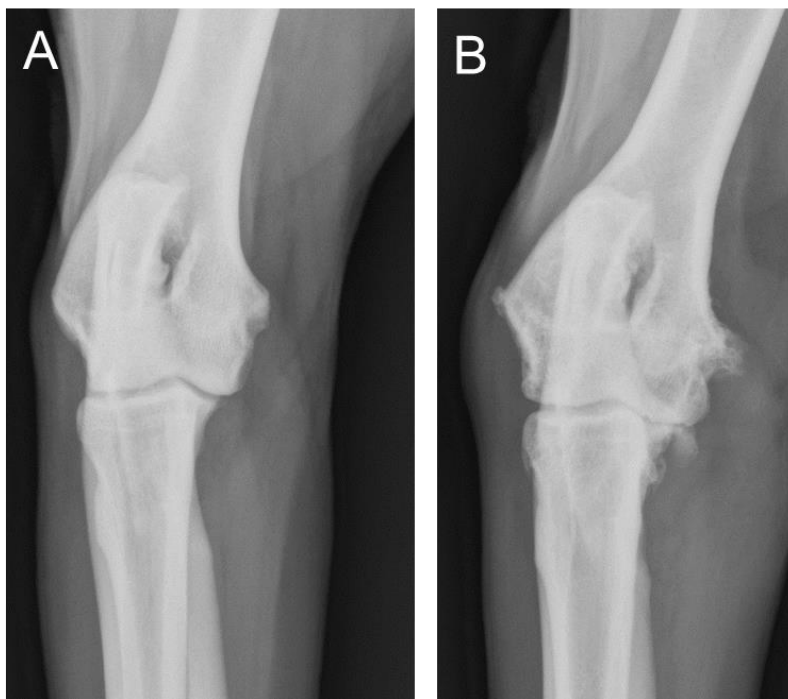
### ***Clinical findings***

Dogs with erosion of the medial compartment are mostly presented with non-specific clinical signs of elbow pathology (4, 8). Most dogs with erosion of the medial compartment demonstrate distinct symptoms such as severe lameness, a limited range of motion, joint effusion, severe pain on elbow manipulation or explicit outward rotation of the affected limb and abduction of the elbow (7). Conversely, it is the authors’ experience that some cases show only mild clinical signs.

### ***Imaging of medial coronoid disease versus medial compartment erosion***

Standard radiographic examination of the canine elbow joint includes 3 projections: a medio-lateral extended view, a medio-lateral flexed view and a 15°-oblique cranio-caudal view (9). As mentioned earlier, diagnosis of medial coronoid disease can be easily missed on radiographic examination due to superimposition of the MCP on the radial head (22). The radiographic diagnosis of cartilage erosions in the canine elbow is even more challenging since only the bony structures are visualized (41). Sclerosis of the subchondral bone and formation of osteophytes and enthesiophytes are typical signs of osteoarthritis that are visible on radiographic examination and are important indicators for elbow disease. In a study of

elbow lameness in dogs of six years and older, the degree of radiographic osteoarthritis was significantly correlated to the extent of the cartilage erosions, although severe erosions were also found without the development of osteophytes (4). In some cases collapse of the medial compartment is visible on the craniocaudal view (41) (Figure 4), which suggests the presence of cartilage erosions. However, care should be taken when evaluating the joint space in non-weight-bearing views. In addition, differentiation between an OCD-lesion of the MHC and a full-thickness cartilage lesion on the MHC can be difficult as well (26). The limitations of radiography were also confirmed in a study demonstrating histological lesions in the cartilage of elbows that were scored as radiographically normal (39, 42).

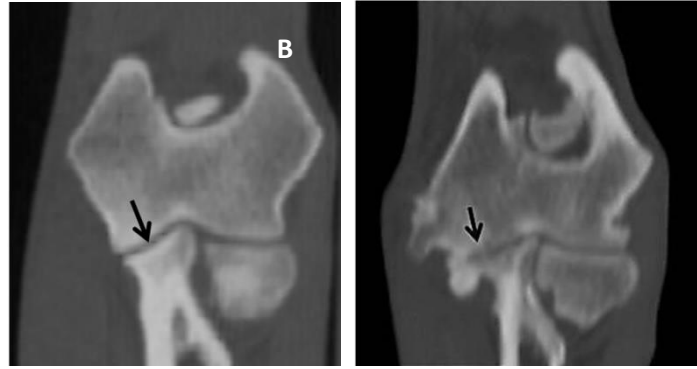


**Figure 4:** A) Craniocaudal radiograph of a normal elbow joint. B) Craniocaudal radiograph of an elbow with erosion of the medial compartment. Severe new bone formation (on both lateral and medial aspect of the elbow), collapse of the medial compartment of the joint and an irregular delineation of the medial part of the humeral condyle is visible.

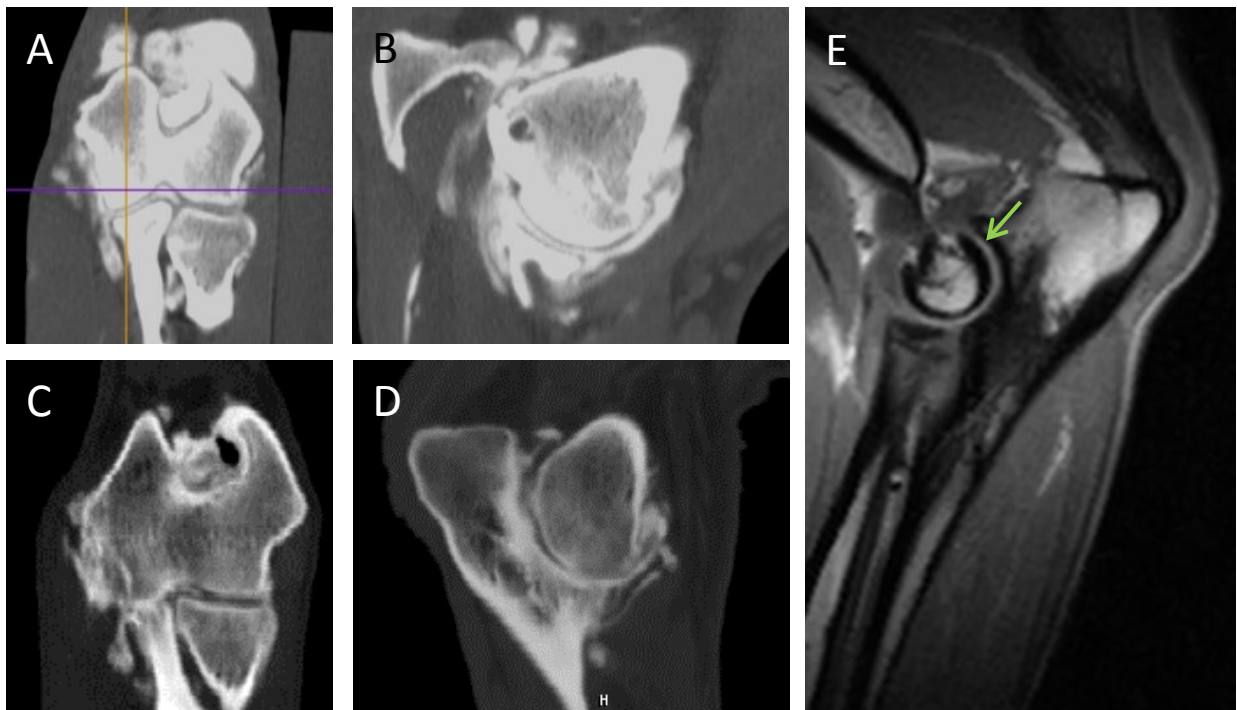
Ultrasound can be a complementary and cost-effective alternative, particularly for the assessment of soft-tissue structures and identifying joint effusion and fragments, combined with radiography (43). However, visualization of bone and cartilage via ultrasound is limited by depth of penetration and ability to clearly distinguish tissue architecture because of the high acoustic impedance of bone (44). Therefore ultrasonography is of limited diagnostic value in detecting fissuring/fragmentation of the MCP and differentiating it from an abnormally shaped MCP due to osteoarthritis (45). Information on the specific diagnosis of

cartilage erosion in the medial elbow compartment via ultrasonography is limited. One study compared ultrasonographic findings with anatomic and radiographic features of the elbow joint. In this study the head of the radius and its hyaline cartilage were imaged but it remains unclear whether lesions of the articular surface of the MCP or the MHC can be visualized (46). In a study on the ultrasonographic appearance of osteochondrosis lesions of the canine shoulder, cartilage lesions were visualized in detail by positioning the probe perpendicular to the humeral head (47). This is not possible in the elbow because of the anatomical structure of the joint forcing the MCP opposite to the MHC in tight apposition.

CT is a routinely applied additional diagnostic technique to identify bony lesions of the elbow joint (48). This technique can reliably identify fissuring or fragmentation of the MCP (12, 48). However, the absence of CT signs does not rule out elbow lesions (12). Direct imaging of cartilage with CT is not possible since CT cannot differentiate cartilage from other soft tissue structures (12) (Figure 5). Cartilage lesions can be estimated indirectly based on the correlation between osteophyte size seen with CT and the degree of cartilage erosions of the elbow joint seen on arthroscopy (12). Similarly, an irregular radial incisure of the ulna on CT was significantly associated with the arthroscopic identification of cartilage erosions of the MCP. However the absence of those lesions on CT does not preclude erosion of the medial compartment (12). More information about the articular cartilage may be provided with CT-arthrography. In human medicine CT-arthrography is being used to evaluate articular cartilage in several joints (49, 50). In veterinary medicine the technique has only been described for the detection of meniscal tears and/or a rupture of the cranial cruciate ligament in the canine stifle joint and in the normal canine elbow and shoulder (51-55). After a survey CT scan, a non-ionic iodinated contrast medium is injected intra-articular and the CT scan is repeated using the same slice orientation, resulting in a positive contrast CT arthrogram (Figure 6) (53). The articular cartilage can be identified as a hypoattenuating zone at the bone-joint interface (51, 54). The optimal volume and contrast medium concentrations, injected in canine joints for CT-arthrography, are not established yet. In the one study on cadaveric canine elbow joints a volume of 6-8 ml of diluted contrast was injected. Three different concentrations (150, 75 and 37.5 mg I/ml) were used, where 75 mg I/ml seemed less optimal for articular cartilage measurements (54).



**Figure 5: Computer tomographic dorsal reconstruction images of a sound elbow (A) demonstrating a normal medial joint space (arrow) and an elbow with erosion of the medial compartment (B) demonstrating explicit narrowing of the medial side of the joint space (arrow) and marked new bone formation.**



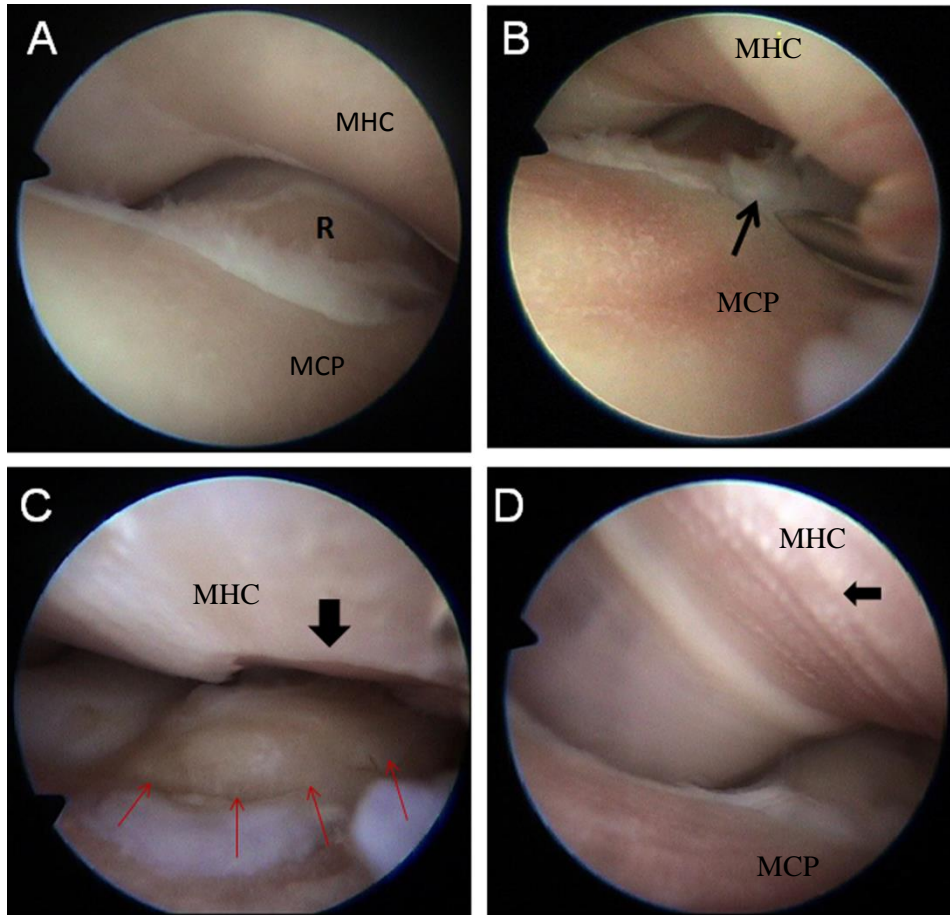
**Figure 6: On the dorsal and sagittal reconstructed CT-arthrography images of a canine elbow with normal cartilage (A, B) contrast filling of the medial joint compartment is visible. The articular cartilage of both the ulna and the MHC can be separately delineated as the hypoattenuating line at the bone-joint interface. On the dorsal and sagittal reconstructed CT-arthrography images of an elbow with medial compartment erosion (C, D) the articular cartilage of the ulna and the MHC cannot be clearly delineated. On the T1-sagittal MRI image of a normal canine elbow (E) the cartilage of both the ulna and the MHC is visible as one isointense line (arrow).**

Scintigraphy is an extremely sensitive tool for the detection of early changes in bone metabolism. It has been used for the localization of occult lameness in small animals and more specifically regarding the diagnosis of elbow lameness in dogs (56). On high resolution micro-single photon emission tomography (HiSPECT) increased activity in the medial epicondylar region was associated with flexor enthesopathy on CT and arthroscopy and increased uptake in the MCP and MHC region with medial coronoid disease (57). However, this functional imaging technique probably will not be able to differentiate cases of medial coronoid disease with or without cartilage erosion.

The gold standard for articular cartilage examination in dogs is arthroscopy, a minimally invasive technique which allows direct inspection of the intra-articular structures (1, 10-12, 38). The color and surface anatomy of the cartilage can be inspected in detail. Typical lesions seen in joints with erosion of the medial compartment are full thickness cartilage lesions with exposure of subchondral bone, showing linear excoriations in advanced cases (modified Outerbridge grades 4-5) (Table 1) (Figure 7). The cartilage of the lateral part of the humeral condyle mainly remains intact and is sharply delineated from the eroded area (4) although visual pathology of the cartilage of the lateral compartment of the elbow joint is occasionally observed (21).

More sensitive diagnostic measures are required to identify those cases with marked cartilage disease and minimal radiographic or computer tomographic pathology. Magnetic resonance imaging (MRI) is regularly used in human medicine to detect osteoarthritic changes. In contrast to human joints, MRI of canine joints is not routinely used to visualize cartilage (58). Due to the low signal-to-noise ratio of most currently available low-field MRI devices in veterinary medicine, the opposing thin cartilage layers of the canine elbow cannot be clearly differentiated (Figure 6) (59). Also the severity of histologic changes in the subchondral bone could not be correlated to MRI findings in the canine elbow joint with medial coronoid disease (60).





**Figure 7: Different presentations of erosion of the medial compartment: A: Left elbow of a 9 year old female crossbreed dog: severe erosion of the medial compartment of the elbow joint without fragmentation of the medial coronoid process. The radial head (R) is also affected. B: Left elbow of 10 year old male Labrador: erosion of the medial compartment of the elbow combined with a very small fragment of the medial coronoid process (arrow). C: Left elbow of 1 year old male American Bulldog: erosion of the medial compartment with a clear wear lesion on the medial part of the humeral condyle (large black arrow), probably caused by the large fragment of the medial coronoid process (small red arrows). D: Left elbow of a 7 year old male Labrador: Erosion of the medial compartment and a distinct delineation with the normal cartilage of the lateral compartment of the joint. Obvious linear excoriations are visible in the diseased area (arrow).**

## **Treatment**

The regeneration capacity of cartilage is limited due to the low cellular mitotic activity of chondrocytes and the lack of direct vascular supply (13, 61). Therefore, treatment of erosion of the medial compartment of the canine elbow is challenging.

### ***Conservative and pharmacologic treatment***

Routinely used treatments for degenerative joint disease can be applied to dogs with erosion of the medial compartment, e.g. NSAIDs (non-steroidal anti-inflammatory drugs), nutraceuticals, platelet-rich plasma, hyaluronic acid, pentosan polysulfate sodium (13, 62-64). However, strong evidence that these products have a positive effect on the cartilage lesions in the canine elbow is lacking.

The routinely applied conservative treatment for degenerative joint disease includes a combination of pain medication, restricted exercise and weight control (65). NSAID's (non-steroidal anti-inflammatory drugs) are effective in moderating the clinical signs of osteoarthritis, but they do not affect the progression of the disease (64). Loss of body weight significantly decreases lameness (66). The effect of nutraceuticals, such as glucosamines and chondroitine sulphate, is variable and product dependent. Some studies have shown that these substances can help to reduce pain caused by degenerative joint disease and other studies show a chondroprotective effect, but the evidence is not very convincing (65).

Intra-articular injections with platelet-rich plasma (PRP) or autologous conditioned plasma (ACP) are suggested for the treatment of joints with large cartilage defects. PRP is a rich source of autologous growth factors, such as transforming growth factor- $\beta$  (TGF- $\beta$ ), insulin growth factor (IGF), and platelet derived growth factor (PDGF) (13, 67) PRP has several advantages: it can be easily obtained from autologous whole blood, is minimally invasive, poses no risk of spreading transmissible diseases and is relatively cheap (13). A positive effect of PRP on bone regeneration and soft tissue healing is reported in several animal studies (13, 68). Recent studies showed also a beneficial effect of PRP on the healing of large osteochondral defects in rabbits (13) and a reduction of pain and improved joint function in human patients with a chronic degenerative condition of the knee (67).

Hyaluronic acid is a natural component of cartilage and synovial fluid which can be used in the treatment of osteoarthritis. A reduction of the chain length and concentration of hyaluronic

acid in the synovial fluid of osteoarthritic joints causes a decreasing ability to lubricate the joint, to absorb loads and exert anti-inflammatory effects (69). In a study with racing greyhounds, intravenous administration of sodium hyaluronate relieved more effectively joint pain than the more conventional intra-articular or intra-muscular administration (70). Studies evaluating the effect of intra-articular hyaluronic acid injections in dogs produced conflicting results. One study suggests that hyaluronic acid injected early after surgery, does not protect the cartilage against erosion (71). Other studies concluded that hyaluronic acid injections reduce cartilage damage (62, 72). The combination of intra-articular injections with PRP and hyaluronic acid for the treatment of degenerative cartilage lesions and osteoarthritis in humans was more effective, with longer mode of action on pain reduction and articular function compared to sole hyaluronic acid injections (73).

Pentosan polysulfate sodium (PPS) is applied in dogs with osteoarthritis. Over the last 4 decades, PPS has been used in man to treat heart and brain infarctions and osteoarthritis in knee and finger joints (63, 74, 75). PPS has multiple effects on osteoarthritis conditions such as reduction of inflammation, improving blood flow in synovium and subchondral bone, stimulation of chondrocytes for normal production of proteoglycans and stimulation of synovium for normal production of hyaluronic acid (63). PPS is administered as a course of four individual injections at seven days intervals (63, 76). Reported side effects in dogs are lethargy, anorexia, reduced activity, vomiting, diarrhea and haemorrhage. Most of these side effects are mild and transitory (76).

### ***General surgical treatment techniques for cartilage erosions***

In general, arthroscopy is performed to confirm the diagnosis of erosion of the medial compartment. When observing a concomitant osteochondral fragment of the MCP (Figure 7), it can be removed immediately (7, 27, 77). In an evidence based medicine (EBM) level 4d study (Table 2) describing the arthroscopic removal of a fragmented MCP as a single treatment in dogs with concomitant severe elbow incongruity (radio-ulnar step > 3mm), some dogs also had modified Outerbridge score 4 cartilage lesions. Despite the cartilage lesions, the dogs had a fair to good long-term outcome. Important limitations of this study included the small amount of dogs (= 8) and the lack of force-plate or motion analysis (77). In addition to fragment removal, several procedures have been described to stimulate spontaneous repair or to induce repair by cartilage transplantation (61, 78-80). However, information is lacking on the long-term results of these techniques.

Arthroscopic abrasion chondroplasty removes damaged cartilage and part of the subchondral bone until bleeding of the underlying tissue is obtained. The formed blood clot covers the debrided area and the fibrin clot converts to fibrous tissue with the subsequent formation of fibrocartilage after a few months (78, 81). Other techniques, such as arthroscopic Pridie-drilling and microfracturing generate small micro-holes across the entire articular cartilage lesion site, thereby stimulating a spontaneous repair reaction similar to the abrasion chondroplasty technique (78). This fibrocartilaginous repair tissue is much weaker than hyaline cartilage. It can only persist for some weeks or months and thus results in poor long-term performance (78, 80).

Other than stimulation of spontaneous repair, autologous perichondral or periosteal grafts can be used to induce repair of articular cartilage defects. However, according to animal and human studies, the outcome of these transplantation methods is highly variable (78, 82). Alternatively, the transplantation of osteochondral tissue (mosaicplasty) within articular cartilage defects offers a fully formed articular cartilage matrix and the potential for transplanting viable chondrocytes (82, 83). The major disadvantage of both techniques is the need of a donor site. Removing osteochondral plugs results in destroying healthy tissue and the translocation of tissue from a low-weight-bearing area to a high-weight-bearing area leads to degeneration (78). A prospective study in human patients with articular cartilage lesions of the knee demonstrated significantly better results after an osteochondral autologous transplantation in comparison to microfracture and debridement procedures (84). The use of autografts is definitely more advisable than allografts, since allografts give rise to problems with preparation, storage and immune reactions (78, 85).

Since autologous and allogeneous tissue/cell transplantation techniques have several limitations and poor clinical performance, tissue engineering has come into sight as a promising technique for cartilage repair (86). Tissue-engineering can be defined as an in vitro reconstruction process to create mammalian tissues. This reconstruction process can be conducted partially or completely in vitro followed by in situ implantation (78). Some models of articular cartilage regeneration have yielded good repair of cartilage defects in animal models and clinical settings in humans (85). Tissue-engineering techniques show a lot of potential to treat cartilage defects, but still a lot of additional research has to be done in the future before its routine clinical application.

***Surgical treatment of erosion of the medial compartment of the canine elbow***

As only the cartilage of the medial compartment of the joint is significantly damaged, surgical techniques transferring the load bearing forces towards the healthy lateral compartment have been developed (Table 3 and 4).

**Table 2: Levels of evidence based medicine (106).**

<b>Grade</b>	<b>Description</b>
1a	Systematic review of randomized controlled trials (RCT)
1b	Individual RCT
2a	Systematic review of cohort studies*
2b	Individual cohort study
3a	Systematic review of case-control studies <sup>o</sup>
3b	Individual case-control study
4a	Lower quality prospective cohort/case control study
4b	Retrospective cohort/case-control study
4c	Case series – describing outcome for one treatment method with no control group
4d	Case series- describing novel aspect of management and providing some information regarding outcome
4e	Lower quality case series – concerns regarding study design and/or ability to interpret information
5	Expert opinion without explicit critical appraisal, or based on physiology, bench research or “first principles”

\*a cohort study is a study that follows a group of patients over a period of time and investigates the effect of a treatment or risk factor.

<sup>o</sup>a case-control study is one that examines the effect of a risk factor on the outcome for a group of patients with a disease compared to that of a matched control group without the disease.

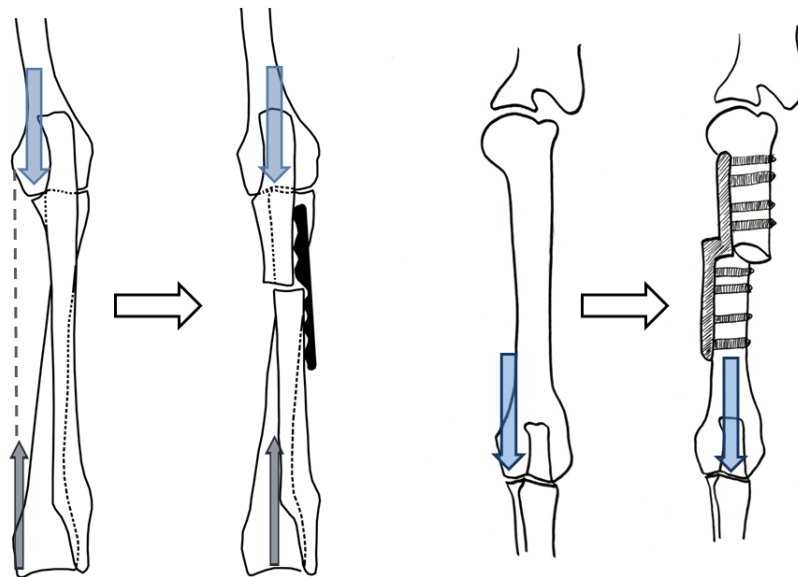
One such load bearing transferring technique is the sliding humeral osteotomy (SHO) (Figure 8). After arthroscopic joint inspection and removal of fragments of the MCP, an osteotomy is performed perpendicular to the long humeral axis and a special SHO-plate is fixed to the medial aspect of the humerus causing lateral transposition of the proximal part of the humerus. This lateral transposition results in reduced loading of the medial joint compartment. The technique was first evaluated in an EBM level 4d study involving 59 elbow joints (49 dogs) with severe cartilage lesions and providing medium-term follow-up of 32 joints. Lameness improved in all 32 joints after 26 weeks and resolved in 21/32 joints. Reported complications were a humeral fracture, screw breakage, delayed osteotomy union and minor surgical wound breakdown. Major complications requiring surgical revision were reported in up to 22.2% (5). More recent data from the same author demonstrate a reduction of the total complication rate to 4.17% (87). However, another recent EBM level 4a study involving 32 dogs (35 elbows) treated with a SHO reported major complications in 17% (88). Care should be taken in advising a SHO for the management of pain and lameness in case of

erosion of the medial compartment. An important concern is the possible development of cartilage lesions in the lateral compartment of the joint after performing SHO. Arthroscopic re-evaluation of some dogs several months postoperatively revealed healing of the previously diseased medial joint compartment with fibrocartilage and demonstrated no visible cartilage disease of the lateral compartment (5, 88). Necropsy in one dog 17 months postoperatively revealed a healthy cartilage cover on the lateral part of the humeral condyle with minimal indication of disease (5). Long-term follow-up with force plate analysis of 7 dogs demonstrated no significant improvements in limb function in 3 dogs (88).

A proximal ulnar osteotomy (PUO) has been proposed as a method to treat radio-ulnar incongruity, a presumed cause of medial compartment overload. Performing a PUO results in a movement of the proximal ulnar segment which may permit re-distribution of forces along the contact areas of the MCP (89, 90). A recent *ex vivo* study demonstrated that PUO is effective in unloading the medial compartment in an incongruent joint (91). A caudoproximal to craniodistal and proximolateral to distomedial oblique osteotomy is recommended to prevent extreme tilting of the proximal ulnar segment (7, 92). The osteotomy should be located proximal to the strong interosseus ligament because a distal ulnar osteotomy will not restore the radio-ulnar contact areas (89). A favorable clinical outcome after performing a PUO was reported in dogs with focal deep cartilage lesions of the MHC, combined with treatment of the fragmentation of the MCP (7, 93). Force plate analysis was performed on 32 elbows at 6 weeks, 12 weeks and 6 months after surgery. A significant improvement in peak vertical force was measured after 6 months (93). Complications were minimal and included infection, superficial inflammation due to self-trauma, excessive proximal segment migration and seroma. A secondary surgical intervention was never required (93). The actual lameness status was not mentioned in this EBM level 5 study and long-term follow-up data were not reported.

An external rotational humeral osteotomy (ERHO) has been described as a technique with a potential beneficial effect in dogs with severe erosion of the medial compartment of the elbow (14). This technique was only evaluated in a cadaveric study, proving a lateral shift of the peak pressure location and the center of pressure, and thus reducing the pressure acting on the ulna. However, the orientation of the effective loading axis depends on the positioning of the leg during weight-bearing, so clinical trials are required to investigate the load shift after ERHO and to evaluate the efficacy of the technique for treating erosion of the medial elbow compartment (14).

Another technique developed to unload the medial side of the canine elbow joint is the proximal abduction ulnar osteotomy (PAUL). A transverse ulnar osteotomy is performed and fixed with a proximal abducting ulnar osteotomy plate (Kyon) with a step of 2 or 3 mm (Figure 8). In an *ex vivo* biomechanical study was illustrated that the PAUL procedure has no effect on medial compartment pressure in congruent elbows but may ameliorate medial compartment pressure in incongruent elbows without creating a medial to lateral load shift (94). In an EBM level 5 study involving 36 dogs with high grade cartilage erosions, complications were registered in 4 dogs, all involving screw breakage or loosening. Half the dogs were presented for re-examination after > 5 months and 73% of these were sound (15). No clinical peer-reviewed studies of this technique are available at the moment and concerns are similar to those for the other load transferring techniques: the risk of creating cartilage damage in the lateral compartment and the lack of long-term follow-up studies using objective measuring techniques.



**Figure 8: The principles of sliding humeral osteotomy (right) and proximal abduction ulnar osteotomy (left): transfer of load bearing forces from the eroded medial to the healthy lateral compartment of the elbow joint.**

A proximal ulnar rotational osteotomy (PURO), consisting of a transverse osteotomy with 30° external rotation of the proximal segment, is also a technique that shifts contact pressures towards the lateral elbow compartment. An *ex vivo* study demonstrated a significant decrease in contact pressure in the medial compartment and an increased pressure in the lateral compartment, but it is unknown whether this procedure would be efficacious *in vivo* (95).

Total elbow replacement and unicompartamental elbow arthroplasty are other approaches to treating erosion of the medial compartment (Table 3 and 4).

The first two total elbow replacement (TER) designs which were recently introduced are the Iowa state (Conzemius) prosthesis and the TATE (Acker) prosthesis (17). Both designs consist of a humeral and radio-ulnar component. The Iowa state design is a non-constrained, stemmed and cemented prosthesis (16) while the TATE elbow system is semi-constrained and uses a cementless resurfacing design (17). An *ex vivo* investigation revealed that the TATE arthroplasty system accurately reproduces the sagittal axis of the elbow, which is a critical factor in the success of functional outcome in human elbow arthroplasty. This finding suggests that the TATE arthroplasty might be less predisposed to component loosening, uneven wear and clinical failure (96). Objective data regarding the functional outcome following TATE implantation are lacking at this moment but available subjective data (EBM level 5) suggest an improvement of limb function up to 1 year after surgery, although mild lameness may persist. This conclusion was based on data obtained from two clinical centers where the TATE prosthesis was implanted in 39 cases (97). An EBM level 4a study evaluating the short-term outcome after TER with the Iowa state design in dogs with severe osteoarthritis led to a satisfactory result in 80% of the dogs (n=20) (98). The major complication rate for the TATE elbow system is 7.7% with a similar minor complication rate (96). Reported complication rates for the Iowa state design are 10% intra-operative complications and 20% postoperative complications (98). Potential complications of a total elbow replacement are infection, luxation and fracture of the humeral condyle, fracture of the ulna and implant loosening (97, 98). The newest semi-constrained TER system is the Sirius prosthesis. The implant consists of a cemented humeral component and a cementless radio-ulnar component that is secured to bone with screws (99). A recent *ex-vivo* study demonstrated a significantly reduced range-of-motion after implantation of the Sirius prosthesis compared to normal elbows (100). Further information about the clinical outcome and complication rate of this Sirius system is scarce at the moment. More long-term clinical evaluation of the currently available systems is required.

The canine unicompartamental elbow (CUE) arthroplasty system replaces parts of the eroded cartilage in the medial compartment of the elbow joint with a synthetic plug on the ulna and a metal implant on the medial aspect of the humerus (99, 101, 102). This unicompartamental technique has some conceptual advantages compared to the total elbow replacement techniques and the load-shifting osteotomies. First, CUE is designed to restore physiologic



medial compartment loading as closely as possible. Secondly, CUE still allows supination and pronation of radius and ulna in contrast to TER where a synostosis is created between the radius and ulna. Third, CUE implantation can be done without violation of the collateral ligaments which may decrease the likelihood of postoperative complications such as joint luxation. CUE also allows several strategies for revision in case of complications (101). Medium- to long-term clinical outcome reported in an EBM level 4c study, involving 103 cases, demonstrated full function in 47.6%, acceptable function in 43.7% and unacceptable function in 8.7% of the cases (102). Minor complications, including delayed union and carpal hyperextension, in 27.2% and serious complications, including non-union, fracture and euthanasia, in 11.7% of the cases were encountered (102). An important limitation of the CUE technique is that only a portion of cartilage is resurfaced. If the cartilage of the lateral compartment is also damaged or the area of resurfacing is insufficient such that bone-on-bone contact still occurs, the dog may suffer persistent pain (101).

A recent *ex-vivo* study reported another type of medial compartment elbow arthroplasty system (103). The ulnar component of this medial unicompartamental elbow prosthesis replaces the cartilage of the MCP, the trochlear notch and the medial part of the anconeal process of the ulna (103), thus replacing a larger area of the cartilage of the medial compartment than the CUE. However, no data are available concerning clinical use and outcome of this type of prosthesis.

Elbow arthrodesis is a salvage procedure that has been abandoned by many surgeons since this complicated surgery leaves a substantial mechanical lameness (104). However, in case of failure of other techniques, arthrodesis of the elbow joint might be the only option left (97).

Sensory denervation of the elbow has been proposed as a possible future treatment method for painful degenerated elbow joints. Similar to the hip, denervation of the elbow has been hypothesized to relieve pain. An EBM level 5 study in four normal dogs demonstrated no sensory or motor deficits of the forelimb after sensory elbow denervation (105). Clinical studies have not been performed so far.

**Table 3: Summary of selected references related to *in vivo* evaluation of the surgical treatment of erosion of the medial compartment of the canine elbow joint. (MHC= medial part of the humeral condyle, PVF= peak vertical force, po= post-operative, NA= not available, SHO= Sliding Humeral Osteotomy, PAUL= Proximal Abduction Ulnar Osteotomy, CUE= Canine Unicompartmental Elbow).**

Author	Type of publication	Treatment method	Number of dogs/joints	Lowest total complications rate reported	Reported complications	Subjective follow-up data	Objective follow-up data (pressure/force plate)
Fitzpatrick et al., 2009 (5)	Peer-reviewed	SHO	59 elbows (49 dogs) with cartilage eburnation of the medial compartment	19%	Humeral fracture, multiple/single screw breakage, delayed osteotomy union, wound breakdown, hematoma	26 weeks po: resolved lameness in 21/32 elbows	Force plate analysis of 7 dogs, >12 months po: 3 dogs showed no improvement in limb function (51).
Wendelburg and Beale, 2014 (88)	Peer-reviewed	SHO	35 elbows (32 dogs) with erosion of medial compartment	31% (14% minor, 17% major)	Infection, broken/loose screws, humeral fractures	Partially short-term, 6-12 months po and >12 months po: improvement in 90% according to owners	Force plate analysis of 20 dogs: 18/20 improvement (only in 50% significant).
Fitzpatrick et al., 2015 (87)	Peer-reviewed	SHO	60 elbows (46 dogs) with end-stage medial coronoid disease	4.2%	Superficial infection, delayed union.	Partially short-term, 6-12 months po and > 12 months po: lameness resolved 49/60 limbs	Force plate analysis of 18 dogs: significant improvement all limbs
Pfeil, 2012 (15)	Proceedings	PAUL	36 dogs with high grade cartilage erosion	11%	Screw breakage, screw loosening	>5 months po: resolved lameness in 13/18	NA
Déjardin, 2012 (97)	Proceedings	TATE	39 dogs	18%	Ulnar fracture, implant loosening, pin migration, screw loosening, wound dehiscence, iatrogenic transection ulnar nerve	NA	Force plate analysis of 6 dogs, 6-12 months po: PVF > contra-lateral side
Conzemius et al., 2003 (98)	Peer-reviewed	Iowa state	20 dogs with elbow osteoarthritis	30%	Intra- and post-operative lateral luxation, intra- and post-operative fracture of the MHC, osteomyelitis	Satisfactory outcome (= increased po vertical force, reduced pain and owner satisfaction) in 80%	
Allen, 2012 (99)	Review	Sirius	NA	NA	NA	NA	NA
Allen, 2012 (99)	Review	CUE	22 dogs	NA	NA	>6 months po: 17/22 good or acceptable elbow function	NA
Cook et al., 2015 (102)	Peer-reviewed	CUE	103 elbows with end-stage articular cartilage loss in medial compartment	11.7% major, 27.2% minor	Delayed/non-union, carpal hyper-extension, implant malpositioning, infection, carpal flexor contraction, fracture	>6 months po: 47.6% full function, 43.7% acceptable and 8.7% unacceptable function	Pressure-sensing walkway in 26 cases: significant improvement 6 months po

**Table 4: Summary of selected references related to *ex vivo* evaluation of surgical treatment methods of erosion of the medial compartment of the canine elbow joint (PAUL= Proximal abducting Ulnar Osteotomy, ERHO= External Rotational Humeral Osteotomy, PURO= Proximal Ulnar Rotational Osteotomy, CUE= Canine Unicompartmental Elbow).**

Author	Type of publication	Treatment method	Number of dogs/joints	Evaluation system	results
McConkey et al., 2016 (94)	Peer-reviewed	PAUL	16 unpaired cadaveric forelimbs	Pressure sensor system	Congruent elbow: no effect on medial contact pressure. Incongruent elbow: decrease in contact pressure medially and no effect laterally.
Gutbrod and Guerrero, 2012 (14)	Peer-reviewed	ERHO	8 cadaveric elbows	Digital pressure sensors in sub-chondral osteotomy distal to the elbow joint	Peak pressure location and center of pressure shifted laterally.
Cuddy et al., 2012 (95)	Peer-reviewed	PURO	12 unpaired cadaveric thoracic limbs	Digital pressure sensors and 3D static elbow poses	Mean and peak contact pressure significantly decreased in medial compartment and increased in lateral compartment.
Burton et al., 2013 (96)	Peer-reviewed	TATE (first generation)	5 pairs of cadaveric forelimbs	Kinematic analysis, using reflective markers	No significant difference in orientation of the elbow axis pre- and post-operative or between left and right.
Lorenz et al., 2015 (100)	Peer-reviewed	Sirius	4 cadaveric forelimbs	Kinematic analysis with 3D motion capture system using reflective markers	Reduced range-of-motion in sagittal plane and for pronation and supination, compared to normal elbows
Smith et al., 2013 (103)	Peer-reviewed	CUE	6 pairs of cadaveric forelimbs	Axial compression using a mechanical testing system	No significant difference between implanted and control limbs in supra-physiological load to failure.

## **Prognosis**

The prognosis for patients with severe erosion of the medial compartment is guarded because of the limited regeneration capacity of cartilage.

The surgical load bearing transferring techniques are promising treatment methods. Unfortunately, the level of evidence for the success of all these procedures is low. Sufficient information on complication rates and long-term clinical and objective follow-up are still lacking. Also the risk of developing lateral compartment erosions after these procedures has to be examined before routinely applying these techniques.

The prognosis after TER is also questionable. Regardless of the design, a major disadvantage of TER are the limited revision options in case of failure (17, 101). Unfortunately, amputation of the leg in case of failure is not an option in most dogs, since elbow dysplasia is typically a bilateral problem.

Regardless of the applied therapy, the owners have to be informed accurately about the complication rate and prognosis in order to have realistic expectations.

## **Conclusion**

Erosion of the medial compartment of the canine elbow is a complex problem which can present as a single lesion or a concomitant condition. Diagnosis is challenging because erosion of the medial compartment does not generate pathognomonic clinical signs and the cartilage cannot be visualized using non-invasive medical imaging techniques. Treatment of the extensive cartilage damage is challenging since the regeneration capacity of cartilage is limited. Despite a variety of therapies the ideal treatment has not yet been developed.

Knowledge about the occurrence of the different presentations of erosion of the medial compartment is limited and detailed information on imaging findings associated with erosion of the medial elbow compartment is lacking. In addition, research into preventive measures addressing the potential causes of this disease might reduce the occurrence of this debilitating condition.

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## **SECTION II**

### **SCIENTIFIC AIMS**



## **SCIENTIFIC AIMS**

Erosion of the medial elbow compartment is considered to be an advanced stage of medial coronoid disease, part of the elbow dysplasia complex. This condition has gained more interest lately and several specific treatment techniques have been developed to address this debilitating disease.

Until now, information on the prevalence of erosion of the medial elbow compartment and typical characteristics of affected joints is limited. Diagnosis is made by direct inspection of the articular cartilage via arthroscopy. However, data on computed tomographic findings associated with erosion of the medial compartment and concomitant pathologies found during arthroscopy are scarce.

Another important aspect is the prevention of this advanced degeneration of the joint. Several techniques have been described to treat medial coronoid disease and are able to resolve lameness, but often lead to a considerable progression of osteoarthritis. The best technique to treat medial coronoid disease and prevent further degeneration of the joint has yet to be determined.

The aims of this thesis were:

1. To report on the arthroscopic, computed tomographic and radiographic findings in dogs with lameness after arthroscopic treatment of medial coronoid disease (**Chapter 1**).
2. To describe the prevalence of the three manifestations of medial compartment erosion and report on the arthroscopic findings in these joints (**Chapter 2**).
3. To describe the computed tomographic findings in elbow joints with erosion of the medial compartment (**Chapter 3**).
4. To evaluate the long-term outcome and the development of osteoarthritis after the treatment of medial coronoid disease in juvenile dogs by a bi-oblique dynamic proximal ulnar osteotomy, without concurrent additional arthroscopic fragment removal (**Chapter 4**).



### **SECTION III**

### **RESULTS**



## **Chapter 1**

**Arthroscopic, computed tomographic and radiographic findings  
in 25 dogs with lameness after arthroscopic treatment of medial  
coronoid disease.**





**Arthroscopic, computed tomographic and radiographic findings  
in 25 dogs with lameness after arthroscopic treatment of medial  
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## **Summary**

The aim of this study was to describe the radiographic, computed tomographic (CT) and arthroscopic findings in the elbow joints of dogs admitted for elbow lameness after arthroscopic treatment of medial coronoid disease (MCD).

The clinical records (2005-2009), including radiographs, CT-images and arthroscopic findings, from the first and second presentation of 25 dogs admitted for elbow lameness after arthroscopic treatment of MCD were retrospectively searched and reviewed.

Twenty-nine joints were included in this study. The mean age at first treatment was 2.2 years. At the second presentation, on average 2.7 years later, an increase of osteoarthritis and cartilage damage was noticed in all joints. Arthroscopic findings near the medial coronoid process (MCP) were: A calcified body in 11 joints (38%), multiple small calcified bodies in 1 joint (3%), loose scar tissue in 12 joints (42%) and immobile scar tissue in 2 joints (7%). Fifteen joints demonstrated concomitant medial compartment erosion. In 3 joints (10%) there was no calcified body or loose scar tissue found and erosion of the medial compartment was the only pathology diagnosed in the coronoid region. Characteristics of flexor enthesopathy were identified in 9 joints (31%) as well.

It can be concluded that arthroscopic treatment of elbow joints, even with limited cartilage lesions, may not resolve lameness in some cases. Calcified bodies or loose scar tissue near the MCP are a frequent finding in these joints.

## **Introduction**

Medial coronoid disease (MCD) is a developmental disorder that is part of the canine elbow dysplasia complex (1-3). It is the main cause of elbow lameness in young dogs and includes fissuring and fragmentation of the medial coronoid process combined with a varying degree of cartilage and/or subchondral bone pathology (3). Recently, MCD has also been described as an important cause of elbow lameness in adult and old dogs (3, 4). MCD can either be treated conservatively or surgically by fragment removal via arthrotomy or arthroscopy (5-7). Arthroscopy has gained more interest over arthrotomy because of the minimal invasive character of the procedure and the fast recovery. Different studies report a good or excellent outcome in 60 to over 90%, based on a follow-up period of 6 months to several years (6, 7). Unfortunately, the outcome is not always favorable and dogs may be represented with lameness despite the treatment. There is no literature on the diagnostic findings in those joints. The radiographic progression of osteoarthritis after the surgical treatment of joint disease is commonly recognized and could partially explain the problem (5, 7, 8). It is known that radiography provides insufficient information about the pathologic changes within the joint, more specifically of the medial coronoid process (MCP) (3). Computed tomography (CT) and arthroscopy may contribute to a more accurate diagnosis, leading to a better understanding of the problem and a correct treatment protocol.

The purpose of this study was to describe radiographic, CT and arthroscopic findings in dogs that were represented with elbow lameness after the arthroscopic treatment of MCD. We hypothesized increased degenerative changes are not the sole pathologic changes present in elbow joints with persistent or recurrent lameness after the arthroscopic treatment of MCD.

## **Material and methods**

### ***Patient records***

Over a period of 5 years (2005-2009), the medical records of patients presented at the authors' institution with elbow lameness after arthroscopic treatment of MCD were selected. Inclusion criteria were: 1) elbow lameness after the arthroscopic treatment of that particular joint; 2) first arthroscopic treatment performed at the authors' institution; 3) complete information on signalment, history, clinical and orthopedic examination at the first and second presentation; 4) a complete set of diagnostic quality radiographs at the first and second examination; 5) CT-examination of the elbow before the first arthroscopic treatment; 6) still or video images of the first and second arthroscopy.

### ***Methods***

The radiographic examination of the elbow at the first and second presentation included a mediolateral extended and flexed view and a craniocaudal (15°- pronation) view. The radiographs were scored for osteoarthritis based on the International Elbow Working Group (IEWG) guidelines (0 = no osteophytes, 1 = osteophytes  $\leq$  2 mm (mild osteoarthritis), 2 = osteophytes 2-5 mm (moderate osteoarthritis), 3 = osteophytes  $>$  5 mm (severe osteoarthritis)) (9). The radiographs from the second presentation were also evaluated for the presence of a visible calcified body at the level of the MCP.

All joints had CT-examination prior to the first arthroscopy. Only 15 joints had CT before the second arthroscopy. CT was performed with a single row detector spiral CT (Prospect, GE Medical Systems, Milwaukee, WI) with a tube voltage of 100 kV and 120 mA. Slice thickness was 1 mm. All dogs were positioned in left lateral recumbency with the front legs parallel and extended cranially. The head of the dogs was pulled back laterally, to avoid interference. Both elbows were scanned at the same time (10). The CT findings were used to increase the accuracy of the first diagnosis and to specify the lesions at second presentation, in case CT was performed. The lesions of the MCP, the medial part of the humeral condyle (MHC) and pathologic changes of the flexor muscles were recorded for the first and second procedure. Flexor enthesopathy characteristics evaluated were the appearance of the medial humeral epicondyle, thickening of the flexor muscles and the presence of a calcified body in the flexor muscles (11).

Arthroscopy was performed by an experienced orthopedic surgeon (BVR or YS) with a 2.4 or 1.9 mm arthroscope (Richard Wolf, Knittlingen, Germany) using a standard medial approach (12). All arthroscopic procedures were documented with digital still and/or video images.

The MCP lesions at the first presentation were categorized based on CT and arthroscopy findings as chondromalacia-like lesions, fissures, non-displaced fragments, displaced fragments and erosion of the medial compartment (table 1) (4, 13). Cartilage lesions of the MCP and MHC were evaluated arthroscopically and scored according to the modified Outerbridge classification (4, 14). A loose cartilage flap of the MHC was recorded as an osteochondritis dissecans (OCD) lesion (15). The flexor muscles and their entheses on the medial humeral epicondyle were inspected and characteristics for flexor enthesopathy such as fibrillation of the insertion of the muscles, an erosion near the insertion site or yellow discolored appearance of the flexor muscles were recorded (16). The arthroscopic images were reviewed for the presence of a radio-ulnar step indicating radio-ulnar joint incongruity. The radio-ulnar incongruity was classified as normal (no step), mild (step < 2 mm) or clear (step ≥ 2 mm). Based on the diagnostic findings, surgical treatment was performed. Treatment consisted of the removal of the fragmented or fissured part of the MCP, followed by an extensive probing and debridement of the remaining part of the MCP to ensure removal of all diseased tissue and to stimulate fibrocartilagenous ingrowth (17, 18). In chondromalacia-like lesions the soft and fibrillated cartilage, in general located at the tip of the MCP, and underlying subchondral bone were removed. OCD-lesions of the MHC were completely removed as well, also followed by debridement of the underlying subchondral bone (18). The procedure was completed after a thorough lavage of the joint. In case of bilateral elbow lameness, arthroscopy was performed in both elbows at the same time.

**Table 1: Overview of the arthroscopic and computed tomographic characteristics of the five types of lesions of the medial coronoid process (4).**

<b>Diagnosis</b>	<b>Arthroscopic findings: medial coronoid process</b>	<b>Computed tomography findings: medial coronoid process</b>
<b>Chondromalacia</b>	Irregular, soft or fibrillated cartilage. No fissure.	No subchondral fissure
<b>Fissure</b>	Cartilage fissure or irregular, soft or fibrillated cartilage. No mobile fragment when probing.	Non-displaced fragment
<b>Non-displaced fragment</b>	Complete fissure. Fragment located at its original position and mobile when probing.	Non-displaced fragment
<b>Displaced fragment</b>	Fragment cranially displaced.	Fragment cranially displaced
<b>Erosion of the medial compartment (as single finding)</b>	Erosion of the medial coronoid process (modified Outerbridge 4-5). No fragmentation.	No fragmentation No subchondral fissure

The identification of the lesions at the second presentation was based on the arthroscopic findings and additional information of the CT-examination, when available. The cartilage damage of the MCP and the MHC was scored according to the modified Outerbridge classification (4). In joints with full thickness cartilage loss with exposure of the subchondral bone (modified Outerbridge grades 4-5) of the MHC and the corresponding ulnar contact area, the term erosion of the medial compartment was used (4, 14). Based on the diagnostic findings, arthroscopic treatment was performed if suitable. In general, tissue that seemed to disturb joint function was removed.

During the second arthroscopic procedure a tissue sample of the lesion near the MCP was preserved in 9 cases. The samples were fixed in phosphate buffered formalin and embedded for light microscopy. Sections were cut and stained with hematoxylin and eosin, Von Kossa's silver stain and Giemsa according to standard procedures.

A non-steroidal anti-inflammatory drug was given during each arthroscopy and prolonged during three weeks postoperatively. The dogs were walked on a leash during six weeks.

Since all of the patients were referral patients, follow-up at our institution was not always possible because of the long distance. Clinical outcome after the second treatment, based on orthopedic examination in our institution and owner evaluation, was available for 14 joints (10 dogs). For another 8 joints (8 dogs) owner evaluation was obtained via a telephone conversation. Presence of lameness, improvement after the second treatment, administration of medication and level of satisfaction were recorded.

## **Results**

### ***Dogs***

The complete files of 25 dogs (29 elbows) with elbow lameness were included in this retrospective study. Eighteen joints with incomplete medical records or arthroscopically treated at a different institution were excluded. Four of the included dogs had a bilateral second arthroscopy. All patients included were large-breed dogs. The breeds are illustrated in table 2. Labrador retrievers (8 dogs, 32%) were most commonly represented. The male:female ratio was 1.8:1.

**Table 2: Breed distribution of 25 dogs with lameness after arthroscopic treatment of medial coronoid disease.**

<b>Breed</b>	<b>Total number of dogs (%)</b>
Labrador Retriever	8 (32%)
Rottweiler	3 (12 %)
Crossbreed	3 (12%)
Bouvier des Flandres	1 (4%)
Airdale Terrier	1 (4%)
American Bulldog	1 (4%)
Appenzeller Sennen hund	1 (4%)
Bull Mastiff	1 (4%)
Chow chow	1 (4%)
Golden Retriever	1 (4%)
Old English sheepdog	1 (4%)
Standard Schnauzer	1 (4%)
Rhodesian Ridgeback	1 (4%)
Weimaraner	1 (4%)
	25 (100%)

The average age at the time of the first treatment was 2.2 years (range 6 months – 5.8 years) and at the time of the second arthroscopy 4.9 years (range 9 months – 10.8 years). Fourteen joints (48%) were treated before the dogs were 1.5 years old. There was an average time of 2.7 years between both arthroscopies (range 3 months – 6.2 years).

### ***Radiographic, computed tomographic and arthroscopic findings at the first presentation***

Radiographic examination before the first arthroscopy demonstrated no osteophytes in 10 joints (35%), mild osteoarthritis in 11 joints (38%), moderate osteoarthritis in 7 joints (24%) and severe osteoarthritis in 1 joint (3%).



The distribution of the initial lesions of the MCP is illustrated in table 3. On arthroscopic inspection, ten joints (35%) had normal cartilage of the medial compartment, except for the coronoid lesion. Sixteen joints (55%) demonstrated mild to moderate cartilage damage (modified Outerbridge grades 1-3) of the MCP and/or MHC. Two of 29 joints (7%) almost had erosion of the medial compartment (MHC: modified Outerbridge grade 4, MCP: modified Outerbridge grade 1-3). One joint (3%) demonstrated erosion of the medial compartment, concomitant to a non-displaced fragment of the MCP. Fifteen joints (52%) showed no radio-ulnar step, 6 joints (21%) showed a mild radio-ulnar incongruence and 8 joints (27%) demonstrated a clear radio-ulnar incongruence on arthroscopic inspection. No significant iatrogenic cartilage lesions were observed. None of the elbows demonstrated pathologic changes at the attachment of the flexor muscles.

**Table 3: Arthroscopic findings at the level of the medial coronoid process, the medial part of the humeral condyle and the enthesis of the flexor muscles at the first and second presentation. (# Amount of elbows)**

	#	Lesion at first presentation	#	Lesion at second presentation
<b>M C P</b>	4	Chondromalacia	2	MCE as single finding
			1	Loose scar tissue
			1	Immobile scar tissue
	14	Fissure	5	Loose scar tissue
			4	Calcified body
			3	Calcified body + flexor enthesopathy
			1	Multiple small calcified bodies
			1	Immobile scar tissue
	5	Non-displaced fragment	3	Calcified body
			1	Loose scar tissue
			1	Loose scar tissue + flexor enthesopathy
	6	Displaced fragment	3	Loose scar tissue
			1	Loose scar tissue + flexor enthesopathy
			1	MCE + flexor enthesopathy
			1	Calcified body
	0	Erosion as single finding	0	-
<b>M H C</b>	4	OCD	2	Loose scar tissue
			1	Immobile scar tissue
			1	Multiple superficial abrasion tracks

Arthroscopic treatment consisted of removal of the fragmented or fissured part of the MCP in 25 joints (86%). In 4 joints (14%) with chondromalacia of the MCP, the tip of the MCP was removed. An additional OCD-flap was removed in 4 joints (14%).

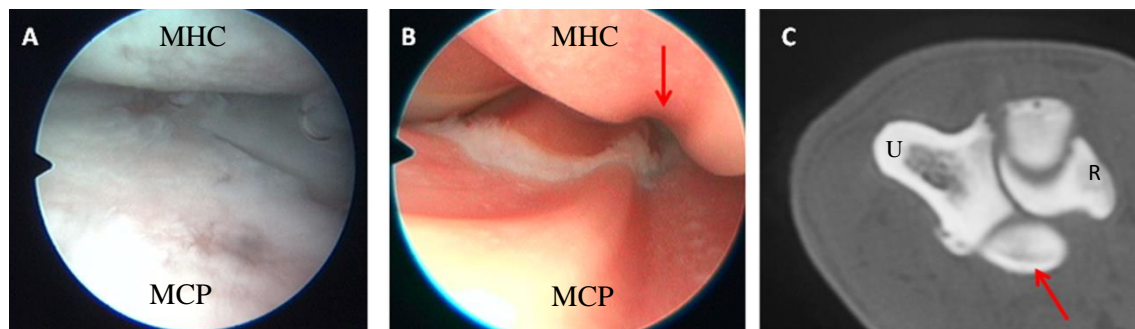
After the first arthroscopy 18 joints (62%, 16 dogs) recovered completely, based on clinical follow-up and/or owner evaluation, but became lame afterwards. Eleven joints (38%, 9 dogs) remained lame after the arthroscopic treatment. Thirteen dogs (17 joints) received NSAIDs

for at least 2 weeks prior to the second arthroscopy. Five dogs (7 joints) received nutraceuticals containing glucosamines in addition. The type of lameness that persisted or recurred after the first treatment varied from a stiff gait to severe lameness. In a few cases lameness was only intermittently visible.

### ***Radiographic, computed tomographic and arthroscopic findings at the second presentation***

At the second presentation, the degree of osteoarthritis on radiographic examination had increased in all joints. Two joints (7%) demonstrated mild osteoarthritis, 14 joints (48%) moderate osteoarthritis and 13 joints (45%) severe osteoarthritis.

CT-images prior to the second arthroscopy were available for 15 joints (52%). The findings at the level of the MCP are described in table 4. In joints with a linear abrasion track on the MHC seen during arthroscopy, CT demonstrated a hypodense linear area on the MHC (Figure 1).



**Figure 1: Arthroscopic image of the first (A) and second (B) presentation of the left elbow from a male Rottweiler at the age of respectively 1.4 and 3.8 years. First chondromalacia of the medial coronoid process was diagnosed (A). At the second presentation (B) erosion of the medial compartment was present with a profound linear abrasion track (arrow) on the medial part of the humeral condyle. The corresponding transverse computed tomographic image of the second presentation (C) demonstrates a hypodense linear area (arrow) on the medial part of the humeral condyle. (MHC: medial part of the humeral condyle, MCP: medial coronoid process, R: Radius, U: Ulna)**

Table 4 describes four types of lesions at the level of the MCP based on the arthroscopic findings and the CT findings, when available. Table 3 shows the evolution of the lesion of the MCP and/or MHC at the first presentation to the second presentation. In all joints, the cartilage damage was substantially more extensive compared to the first presentation. Eighteen of 29 joints (62%) demonstrated erosion of the medial compartment (modified Outerbridge grades 4-5) and one joint (3%) almost developed erosion of the medial compartment (MCP: modified Outerbridge grade 4, MHC: modified Outerbridge grade 3). Nine of 29 joints (32%) demonstrated moderate cartilage damage of the medial compartment (modified Outerbridge grade 2-3). In one joint (3%) the MCP still had normal cartilage

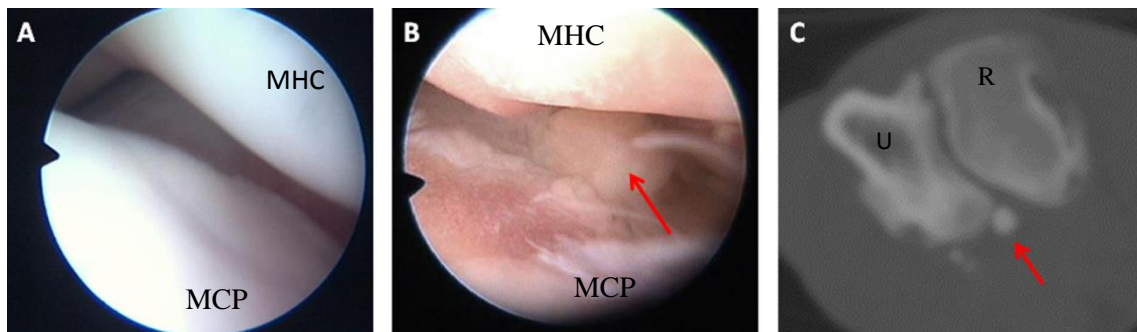
combined with some damage of the MHC (modified Outerbridge grade 2). Findings at the level of the MCP were: A calcified body in 11 joints (38%) (Figure 2), multiple small calcified bodies in 1 joint (3%), loose scar tissue in 12 joints (42%) (Figure 3) and immobile scar tissue at the MCP was found in 2 joints (7%). In 3 joints (10%) there was no calcified body or loose scar tissue found and thus erosion of the medial compartment was the only pathology diagnosed in the coronoid region (Figure 4). In 6 joints (21%) a linear abrasion track was found on the MHC. In 2 joints (7%) loose scar tissue and in 1 joint (3%) immobile scar tissue was found on the MHC where originally an OCD-lesion was removed.

**Table 4: Arthroscopic and computed tomographic findings at the second presentation: description of the findings in 4 groups of lesions of the medial coronoid process.**

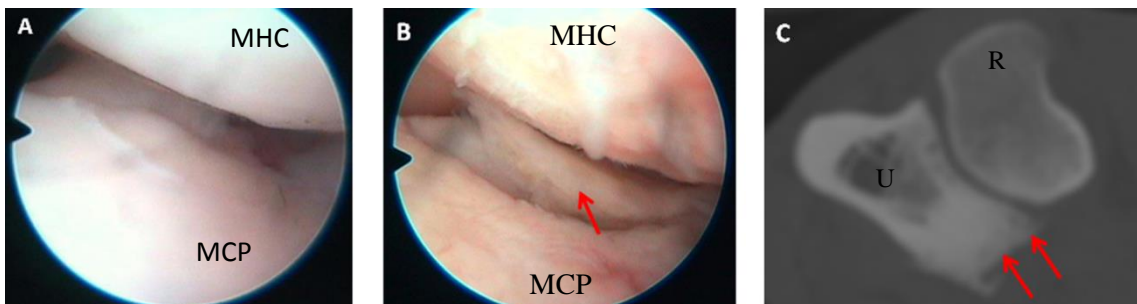
<b>Diagnosis</b>	<b>Amount of joints on arthroscopy</b>	<b>Arthroscopic findings at the level of the medial coronoid process</b>	<b>Amount of joints on CT</b>	<b>Computed tomography findings at the level of the medial coronoid process</b>
<b>Loose scar tissue</b>	12	Loose, irregular fibrocartilaginous tissue. Mobile and soft when probing. No calcified body, except mini-calcifications (< 1mm).	6	Heterogeneous aspect with hypodense areas. Blunt shape. Sometimes mini-calcifications (<1mm) cranially of the remaining part of the medial coronoid process
<b>Calcified body</b>	11	Loose, well-defined rounded fragment with a smooth surface and a hard texture when probed.	6	Rounded fragment, mostly cranially of the remaining part of the medial coronoid process.
<b>Erosion of the medial compartment (as single finding)</b>	3	Erosion of the remaining part of the medial coronoid process (Outerbridge 4-5). No fragment or loose fibrocartilaginous tissue.	2	Heterogeneous aspect with hypodense areas. Blunt shape .
<b>Immobile scar tissue</b>	2	Irregular fibrocartilaginous tissue. Soft and immobile when probing. No calcified body.	1	Heterogeneous aspect with hypodense areas. Blunt shape.

Radiographic examination clearly visualized a calcified body at the level of the MCP in 4 joints (14%). In all 4 of these joints a calcified body was actually found during arthroscopy. In 18 joints (62%) there was no fragment visible on the radiographic examination. However, a calcified body was found in 5 of these joints and multiple calcified bodies in 1 of these joints. In the remaining 7 joints (24%) the presence of a calcified body was unclear on radiography. A calcified body was actually found during arthroscopy in 2 of these joints. In joints with a calcified body, CT images were always positive. The appearance of these calcified bodies on

CT was mostly different from a typical fragmented coronoid process since the calcified bodies were rounded and located cranially of the MCP. In joints with loose scar tissue, the MCP often had a blunt shape and always a heterogeneous aspect with hypodense areas on CT-examination (Figure 3). However, a heterogeneous aspect of the MCP on CT-examination was also recognized in joints with the diagnosis of erosion of the medial compartment on arthroscopic inspection. On arthroscopy, loose scar tissue and calcified bodies were generally easy to differentiate based on their arthroscopic appearance and the palpable hard texture of the calcified bodies.



**Figure 2:** Arthroscopic image of the first (A) and second (B) presentation of the left elbow from a Labrador retriever at the age of respectively 7 months and 6.8 years. First a fissure of the medial coronoid process was diagnosed (A). At the second presentation (B) erosion of the medial compartment is visible and a calcified body (arrow) is present as well. The corresponding transverse computed tomographic image of the second presentation (C) also clearly visualizes the rounded calcified body (arrow). Some secondary osteoarthritic changes are visible as well at the radius (R) and the ulna (U).

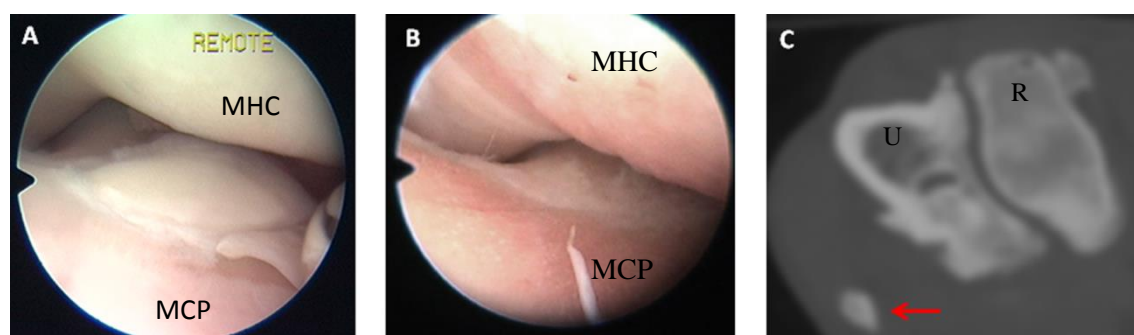


**Figure 3:** Arthroscopic image of the first (A) and second (B) presentation of the left elbow from a Appenzeller Sennen Hund at the age of respectively 2.6 and 5.2 years. First a fissure of the medial coronoid process was diagnosed (A). At the second presentation (B) increased cartilage damage and loose scar tissue (arrow) was present. The corresponding transverse computed tomographic image of the second presentation (C) shows a heterogeneous aspect of the medial coronoid process with hypodense areas (arrows).

In 25 joints (87%) treatment consisted of the arthroscopic removal of loose scar tissue of the MCP and/or MHC or a calcified body near the MCP. Immobile scar tissue did not seem to disturb joint function and was left in place. In 1 joint (3%) where erosion of the medial compartment was the single pathologic finding, part of the eroded MCP was removed. In 2

joints (7%) an additional intra-articular injection with hyaluronic acid was administered and in 3 other joints (10%) no further arthroscopic treatment was performed, except a lavage of the joint.

CT demonstrated signs of flexor enthesopathy in 8 joints (28%). Spur-formation on the medial humeral epicondyle was visible on CT in 4 joints (14%), thickening of the flexor muscles was visible in 2 joints (7%) and a calcification in the flexor muscles was found in 2 joints (7%) (Figure 4). In 4 of these joints arthroscopy also demonstrated loose fibers at the enthesis of the flexor muscles and in 1 joint a yellow discolored appearance of the enthesis of the flexor muscles was visible. In 1 joint without prior CT, arthroscopy also demonstrated fibrillation of the enthesis of the flexor muscles. So when combining CT and arthroscopic findings 9 joints displayed signs of flexor enthesopathy. Calcification of the flexor muscles was found concomitant to loose scar tissue in one joint and concomitant to erosion of the medial compartment in another joint. The loose scar tissue was removed, as already mentioned above. However, both dogs clearly expressed pain during palpation and pressure on the flexor muscles and crepitation in that area was noticed as well. Therefore, a transection of the flexor muscles at the enthesis and removal of the calcification in the muscle was performed as well. In the other joints the flexor enthesopathy was considered concomitant to the coronoid lesion, and thus treatment addressed the coronoid lesion.



**Figure 4:** Arthroscopic image of the first (A) and second (B) presentation of the left elbow from a Labrador retriever at the age of respectively 8 months and 6.8 years. First a displaced fragment of the medial coronoid process was diagnosed (A). At the second presentation (B) erosion of the medial compartment was diagnosed. The corresponding transverse computed tomographic image of the second presentation (C) shows a heterogeneous aspect of the medial coronoid process. In addition, a calcification is visible in the flexor muscles (arrow).

### *Outcome after second arthroscopy*

Follow-up information was available of 22 joints (table 5). The average follow-up period was 2.3 years (range 3 months – 7 years). An improvement of lameness was noticed in 13 joints (59%), of which 3 joints became sound and 10 joints maintained some lameness. For five of

the latter 10 joints treatment with non-steroidal anti-inflammatory drugs (NSAIDs) was sometimes necessary and 3 of those joints were additionally injected with platelet rich plasma and/or hyaluronic acid. No improvement of lameness was noted in 9 joints (41%), of which 7 joints were regularly treated with NSAIDs. Removal of loose scar tissue or a calcified body resulted in an improvement of lameness in 11 joints and lead to no improvement in 8 joints. Owners were satisfied with the outcome after the second arthroscopy of 10 joints (45%) and unsatisfied with the outcome of 12 joints (55%). One dog with a bilateral elbow problem was euthanized because of the persistent lameness.

**Table 5: Outcome after second arthroscopy based on clinical examination of the dog or telephonic contact with the owner. Improvement of lameness was divided in 3 categories: No improvement, improvement of lameness but still lame, and sound (no visible lameness anymore). In addition, owners were asked if they were satisfied with the result or not. (# amount of elbow joints)**

	#	Follow-up period after 2nd arthroscopy	#	Improvement of lameness	#	Owner evaluation
C L I N I C A L	14	3 months- 7 years	3	Sound	3	Satisfied
					0	Unsatisfied
			7	Improvement but some lameness	5	Satisfied
					2	Unsatisfied
			4	No improvement	0	Satisfied
					4	Unsatisfied
T E L E P H O N E	8	1-3 years	0	Sound	0	Satisfied
					0	Unsatisfied
			3	Improvement but some lameness	2	Satisfied
					1	Unsatisfied
			5	No improvement	0	Satisfied
					5	Unsatisfied

### *Histopathological findings*

Tissue samples were available from 9 elbows with a calcified body near the MCP. The samples were composed of dense collagen. Interspersed between the collagen bundles there were small mature fibrocytes. Several fragments contained central cores of ossification and mineralization, which stained positive with Von Kossa's silver stain. There were areas with proliferating and hypertrophic chondrocytes, surrounded by small areas of chondroid matrix.

The latter stained metachromatic with Giemsa stain. Some fragments were partly covered with synovia.



## **Discussion**

It is known that the arthroscopic treatment of MCD cannot always resolve lameness and that it often leads to a considerable progression of radiographic osteoarthritis (7, 8, 19, 20). According to the findings of this study, re-examination of those relapsed joints often reveals a calcified body or loose scar tissue at the level of the MCP, combined with further degeneration of the joint.

The prognosis after surgical treatment of MCD varies and depends on several factors (21). In general, surgical treatment is recommended and associated with the best prognosis in young dogs with clinical or radiographic signs of MCD (21, 22). Fourteen joints (48%) included in this study were treated before the age of 1.5 years and yet the dogs represented with elbow lameness.

Our findings suggest that the calcified bodies found on second-look arthroscopy were not overlooked initially, but were formed over time. CT-examination was performed prior to the first arthroscopy to ensure identification of all fragments or fissures present in the joint. Furthermore, the joints included were exclusively treated at the authors' institution, where arthroscopy is being performed for over 20 years, and still and video images illustrated the complete removal of the fissured/fragmented MCP during the first procedure. This is supported by the histopathological examination: the preserved tissue samples were composed of dense collagen presenting areas of metaplastic cartilage formation and ossification. So the calcified tissue samples seemed to be of a rather degenerative metaplastic nature, but the exact etiology of the described calcified bodies remains unclear. It is known that the chondrocytes of MCP fragments remain viable (23). It is described that osteochondral or cartilaginous fragments in dogs with a fragmented MCP or OCD may become larger than the corresponding subchondral defect, probably by establishing a new blood supply (24, 25). Possibly, the described calcified bodies originated from a miniscule remnant of the removed fragment of the MCP in a similar way. However, these calcified bodies might also develop in dysplastic elbow joints that never underwent arthroscopic treatment or in joints with a good outcome after treatment.

In part of the joints loose scar tissue was found. Since the arthroscopic removal of pathologic tissue results in a bony defect, ingrowth of scar tissue is evident. However, when the scar tissue loosens it might irritate the joint and disturb normal joint function. Loosening of the



scar tissue might be caused by the same chronic overload that is assumed to cause fissuring/fragmentation of the MCP (26). It is unknown whether loose scar tissue also occurs in dogs that recover completely after the arthroscopic treatment of MCD. Further research is necessary to confirm if loose scar tissue can cause elbow lameness.

Abnormalities at the enthesis of the flexor muscles or a calcification in the flexor muscles was found in 9 joints (32%) in this study. Flexor enthesopathy has been described as a differential diagnosis for elbow lameness in dogs (11, 27, 28) and can be considered primary when no other underlying pathology of the elbow joint can be identified. It has also been described concomitant to other elbow pathologies and after treatment of MCD (11). In this study a calcification in the flexor muscles causing pain on palpation was the most prominent finding in 2 joints and could be considered as the primary cause of lameness. However, in the other joints with characteristics of flexor enthesopathy it was unclear whether lameness was caused by the presence of the loose scar tissue or the calcified body or by the flexor enthesopathy. No signs of flexor enthesopathy were found in those joints at the time of the initial arthroscopic treatment. Possibly, trauma caused by the arthroscopic procedure or chronic increased inflammation may have induced the development of this enthesopathy (11).

Despite treatment, cartilage degeneration progressed substantially in all joints. Erosion of the medial elbow compartment was found in eighteen joints and can be a cause of lameness (4, 14, 29). The cause of this continued cartilage degeneration in all joints is unclear. Cartilage damage may have been induced by the arthroscopic treatment itself, since removal of a part of the MCP causes an interruption in joint surface. Incongruity may have induced an increased pressure and subsequent cartilage loss of the medial compartment. However, in this study, radio-ulnar incongruity was observed in less than half of the joints.

An increase of radiographic osteoarthritis was noticed in all joints by the time of the second presentation. It is not clear whether osteoarthritis was the cause of the elbow lameness after the first treatment or whether osteoarthritis was a consequence of the problem that caused a negative outcome. Progression of radiographic osteoarthritis has also been described in joints with a good clinical outcome after arthroscopic treatment (7, 30). A large follow-up study, including CT and arthroscopic findings, comparing successfully treated joints to joints with a negative outcome might answer this question.

Radiography is insufficient to diagnose coronoid lesions because of superimposition of joint structures (31). This study illustrates that the radiographic identification of a calcified body at

the second presentation is doubtful as well. However, a calcified body found during the second arthroscopy was always identified on CT. The appearance was mostly different from the typical medial coronoid lesions because of the rounded shape and cranial displacement. Nevertheless, CT may demonstrate similar findings, such as a heterogeneous aspect of the MCP, in joints with loose scar tissue or erosion of the medial compartment. For the detection and distinction of those lesions, arthroscopy is indispensable (7, 12).

Treatment decision-making was often difficult in these relapsed joints. In general, treatment decision was based on the findings during the clinical examination and the surgeon's experience. The general approach was to remove tissue that seemed to disturb joint function and therefore treatment did not always address erosion of the medial compartment specifically. It was not within the scope of this study to evaluate the results of treatment of these relapsed joints. Different treatments were performed and follow-up was only available for part of the joints. In general, the applied treatment of these relapsed joints resulted in an improvement of lameness in 59% of the joints, but only 45% of the owners was satisfied with the result. More information/research on treatment and treatment results of relapsed joints would be useful to create realistic expectations with the owners.

A limitation of this study is the small amount of joints investigated. This study only included joints that underwent the first and second arthroscopy at our hospital and excluded 18 joints because of incomplete records or arthroscopic treatment at a different institution. In addition, the admission for a second arthroscopy depended on several factors. First, the estimated prognosis at the first treatment influenced the expectations of the owners. Secondly, the perception of lameness and motivation of the owner determined if the dog was represented at the local veterinarian or at the hospital. Thirdly, the judgment and experience of the local veterinarian influenced the decision to refer the dog for a second arthroscopic intervention. Considering the fact that about 200 elbow arthroscopies are performed yearly at the authors' institution and literature describes a negative outcome in at least 10% of the cases (6, 7), the amount of joints included in this study probably underestimates the prevalence of elbow joints that might benefit from a second arthroscopic surgery. The small amount of joints included also interfered with the ability to determine significant correlations for example between the initial lesion and the findings at second presentation. A second limitation is the lack of a control group of joints with a good outcome after arthroscopic treatment and joints that did not undergo arthroscopic treatment.

The diagnostic findings of the 29 joints described in this retrospective study encourage the use of CT and arthroscopy to reveal the cause of lameness in unresponsive cases and help to interpret the different imaging findings in those cases. This study warrants that the outcome after arthroscopic surgery is not always good and that CT and/or arthroscopy might reveal a calcified body which was not necessarily overlooked initially but has formed over time. From the results of this study the exact cause of lameness in these relapsed joints remains mostly unclear and thus also the correct treatment remains debatable. To answer several questions raised by this study, further research including large arthroscopic follow-up studies of elbow joints with satisfactory and unsatisfactory outcome after arthroscopic treatment of MCD is required. Nevertheless, this study demonstrates that when dealing with relapsed joints one should not only focus on the increased degenerative changes, but also on additional lesions like a calcified body or loose scar tissue in the medial joint compartment as a possible cause of lameness.

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## **Chapter 2**

### **Spectrum of arthroscopic findings in 84 canine elbow joints diagnosed with medial compartment erosion.**





**Spectrum of arthroscopic findings in 84 canine elbow joints  
diagnosed with medial compartment erosion.**

*Adapted from: Coppieters E., de Bakker E., Broeckx B., Samoy Y., Verhoeven G., Van der Vekens E., Van Ryssen B. Spectrum of arthroscopic findings in 84 canine elbow joints diagnosed with medial compartment erosion. Veterinary Comparative Orthopaedics and Traumatology 2016, in revision.*



### **Summary**

The aim of this study was to report on the arthroscopic findings associated with medial compartment erosion of the canine elbow joint. Retrospectively, records of 84 elbow joints from 66 dogs diagnosed arthroscopically with medial compartment erosion were retrieved from a medical records database (2008 - 2012). The radiographic degree of osteoarthritis was determined. Arthroscopic images and videos were evaluated in detail.

In 9 joints (10.7%) medial compartment erosion was the only pathological finding (= Group 1). Group 2 (n = 50, 59.5%) consisted of elbows with medial compartment erosion concomitant with medial coronoid process (MCP) pathology. In Group 3 (n = 25 joints, 29.8%), erosion of the medial compartment was diagnosed during a second-look arthroscopy in dogs presented with lameness after arthroscopic treatment for medial coronoid disease. There was a significant age difference ( $p < 0.001$ ) between the groups, with dogs in Group 1 being the oldest. Complete erosion of the medial compartment was most commonly found in Group 1, whereas focal cartilage erosion was mostly identified in Group 2. Overall, additional cartilage pathology of the lateral part of the humeral condyle and/or the radial head was recognized in 58.3% of the joints (49/84).

This study demonstrates the prevalence of the three groups of medial compartment erosion, describes the extent and location of the cartilage lesions in the medial elbow joint compartment and illustrates the cartilage damage of the lateral compartment in more than half of the joints. These findings may contribute to the search for the ethiopathology and treatment strategy of medial compartment erosion.

## **Introduction**

Elbow dysplasia is an important cause of forelimb lameness in large breed dogs (1-3). The elbow dysplasia complex includes several pathologies such as osteochondritis dissecans (OCD) of the medial part of the humeral condyle (MHC), an ununited anconeal process, joint incongruence and disease of the medial coronoid process, combined with a varying degree of cartilage damage (1-3). Radioulnar incongruity is believed to be an important factor in the development of elbow dysplasia because of chronic supraphysiologic loading of the medial joint compartment (4-7). A histological study demonstrated fatigue microdamage in the region of the medial coronoid process (MCP) in dogs diagnosed with a fragmented MCP, supporting the hypothesis of chronic overload of the medial compartment in dysplastic elbows (8). In a more advanced stage of medial coronoid disease, full thickness cartilage lesions with exposure of the subchondral bone (modified Outerbridge grade 4-5) (9-12) of the medial part of the humeral condyle (MHC) and the corresponding ulnar contact area develop (9-11). This advanced cartilage damage can be referred to as medial compartment erosion (11). It seems likely that fragmentation of the MCP and erosions of the medial compartment are attributable to a common pathway (1).

Clinical signs of medial compartment erosion are similar to other lesions in the elbow dysplasia complex (10-13). However, most dogs with erosion of the medial elbow compartment demonstrate marked clinical abnormalities such as obvious lameness, limited range-of-motion or signs of severe pain on elbow manipulation (11). Furthermore, little information is available on the type of dogs affected by medial compartment erosion and the underlying pathology. Therefore, it is difficult to diagnose this condition based on the history and clinical examination. Routinely used imaging techniques such as radiography and computed tomography cannot visualize articular cartilage (11, 14). Arthroscopic inspection of the joint, the gold standard for articular cartilage evaluation (15, 16), is the most reliable method to diagnose medial compartment erosion. The modified Outerbridge classification (12) is the best-known and most commonly used grading system to evaluate cartilage pathology based on the appearance of the articular surface and the depth of the lesions (10-12, 17). Currently, description of erosion of the medial compartment is based on the modified Outerbridge classification grade of the MHC and the corresponding ulnar contact areas. Detailed information on the exact location or the extent of the lesions is lacking.

Medial compartment erosion is reported in three situations: As a single pathology, as a concomitant finding with MCP pathology and/or OCD of the MHC, or as a finding during second-look arthroscopy in dogs with persistent or recurrent lameness after initial arthroscopic treatment of medial coronoid disease (10, 11, 13, 18, 19). The prevalence of those three groups in joints with medial compartment erosion has not been reported yet.

Medial compartment erosion can be treated by load-transferring techniques or unicompartmental arthroplasty systems (9, 20-24). The extent of the cartilage damage within the medial joint compartment, for example cartilage damage expanding into the ulnar trochlear notch, might influence prognosis after treatment. In addition, these techniques require healthy cartilage of the lateral joint compartment. Although it has been reported that pathology of the lateral compartment is less commonly observed (9), the prevalence in joints with medial compartment erosion has not been established yet. Therefore it is difficult to determine the number of dogs that would benefit from those treatment options.

The aim of this retrospective study was to report on the arthroscopic lesions in dogs with medial compartment erosion, determine the associated radiographic degree of osteoarthritis, describe the prevalence of the three groups in elbow joints with erosion of the medial compartment, and report on the prevalence of concomitant lesions of the lateral compartment. This knowledge may facilitate the diagnosis and treatment decision-making in the future.

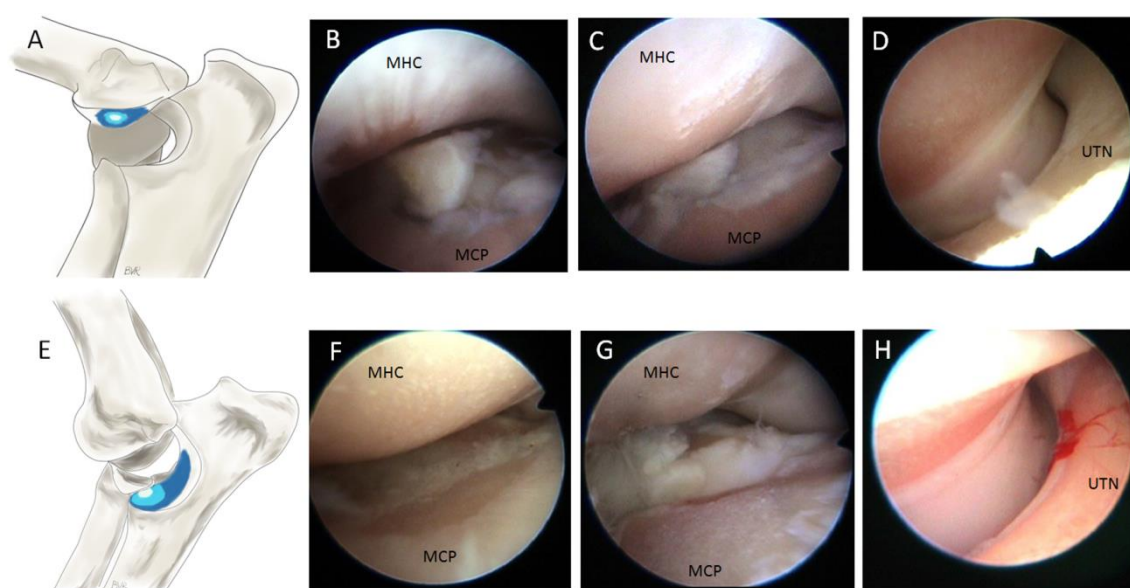
## **Materials and methods**

In this retrospective study, medical records of dogs that underwent elbow arthroscopy at our institution, from 2008 to 2012, were reviewed. To be included in this study the following inclusion criterion had to be met: 1) clear elbow lameness and arthroscopic diagnosis of medial compartment erosion (modified Outerbridge grade 4-5 of the MCP and MHC); 2) complete information about signalment, history, clinical and orthopaedic examination; 3) a complete set of diagnostic high quality radiographs made 1 day to 3 weeks prior to the arthroscopic joint inspection; 4) still and video images of the arthroscopic inspection of the joint when diagnosed with medial compartment erosion; and 5) still and video images of the first arthroscopy in patients diagnosed with erosion of the medial compartment during a second-look arthroscopic procedure. Data collected from the medical records included: gender, age at diagnosis, breed, duration of lameness, body weight, and in some cases, time between the first and second arthroscopy. In case of dogs re-presented with lameness after the arthroscopic treatment of medial coronoid disease, the duration of lameness between the first and second arthroscopic treatment was considered. Twenty-two elbows diagnosed with medial compartment erosion via arthroscopy were excluded because the inclusion criteria were not met. In case of bilateral diagnosis of medial compartment erosion, both elbow joints were included in the study.

Radiographic examination of the elbows included an extended and flexed mediolateral view and a craniocaudal (15°-pronation) view. Radiographs were evaluated to determine the degree of osteoarthritis: 0 = no osteophytes, 1 = osteophytes  $\leq$  2 mm, 2 = osteophytes 2-5 mm and 3 = osteophytes  $>$  5 mm (25).

Arthroscopy was performed with a 2.4 or 1.9 mm, 25° fore-oblique arthroscope (Richard Wolf, Knittlingen, Germany) using a standard medial approach (15). Digital still and video images were taken of all elbow joints. The arthroscopic findings were assessed by the first author and an experienced orthopaedic surgeon together, until a consensus was reached. In patients with medial compartment erosion, the extent of the cartilage lesions of the MHC and the MCP was evaluated and scored as focal, diffuse or complete erosion (Figure 1) (24, 26). Radioulnar incongruity of the joint was evaluated, as previously reported by Wagner et al., at the base, midbody and apex of the MCP (27). Joints were classified as normal (no step), mildly (step  $<$  2 mm) or severely (step  $\geq$  2 mm) incongruent. Pathology of the lateral joint compartment, including the radial head and the lateral part of the humeral condyle, was also

recorded. Additionally, the presence of fissuring or fragmentation of the MCP and/or OCD of the MHC was recorded. After the retrospective evaluation of the radiographs and the data obtained by arthroscopy, the elbow joints were divided in three groups: Group 1 = medial compartment erosion as a single pathology, Group 2 = medial compartment erosion concomitant with a fragmented/fissured MCP and/or OCD and Group 3 = medial compartment erosion at second-look arthroscopy in dogs with persistent or recurrent lameness after arthroscopic treatment of medial coronoid disease (10, 11, 13, 18, 19). For joints to be included in Group 1, the absence of a concomitant fragment or fissure of the MCP needed to be confirmed by computed tomographic examination performed prior to the arthroscopy. The initial arthroscopic treatment performed in the joints of Group 3 consisted of removal of the fragmented or fissured part of the MCP and debridement of the remaining part of the MCP. All dogs in Group 3 were clearly lame according to the owner and the veterinarian at the time of the second-look arthroscopy.



**Figure 1:** Schematic representation of the extent of the cartilage erosion on the medial part of the humeral condyle (MHC) (A) and the medial coronoid process (MCP) (E), and corresponding arthroscopic images, obtained via a standard medial approach (15), illustrating focal (B and F), diffuse (C and G) and complete (D and H) erosion of the MHC (Top row) and the MCP (Lower row) in elbow joints with medial compartment erosion. A, E: Focal erosions are very localized full-thickness cartilage erosions (White area). Diffuse erosions affect the majority of the cartilage surface of the MCP or the MHC but the cartilage of the trochlear notch or the corresponding humeral cartilage is still intact (Light blue area). Complete erosions affect the entire surface of the MHC or the MCP including the cartilage of the ulnar trochlear notch (UTN) and the corresponding humeral cartilage (Dark blue area).

### ***Postoperative care***

The dogs were released on the same day as the arthroscopic treatment. The dogs received a non-steroidal anti-inflammatory drug for three weeks. For all dogs, restricted exercise with leash walks was advised for a period of six weeks postoperatively.

### ***Statistical analysis***

Age and duration of lameness were compared for the three groups by the non-parametrical Kruskal-Wallis test. Post-hoc comparisons were done using the Wilcoxon rank sum test with the Bonferroni- correction. A Fisher-exact test with Monte Carlo simulation (2000 replicates) was performed to examine the relation between group and degree of osteoarthritis, incongruity, extent of MCP and MHC lesions, presence of linear abrasion tracks, presence of white areas and damage of the lateral compartment. Results are reported as percentages, median and range when appropriate. Statistical analysis was conducted with R (version 3.1.2, “Pumpkin Helmet”) (28). Significance was set at  $P < 0.05$ .



## **Results**

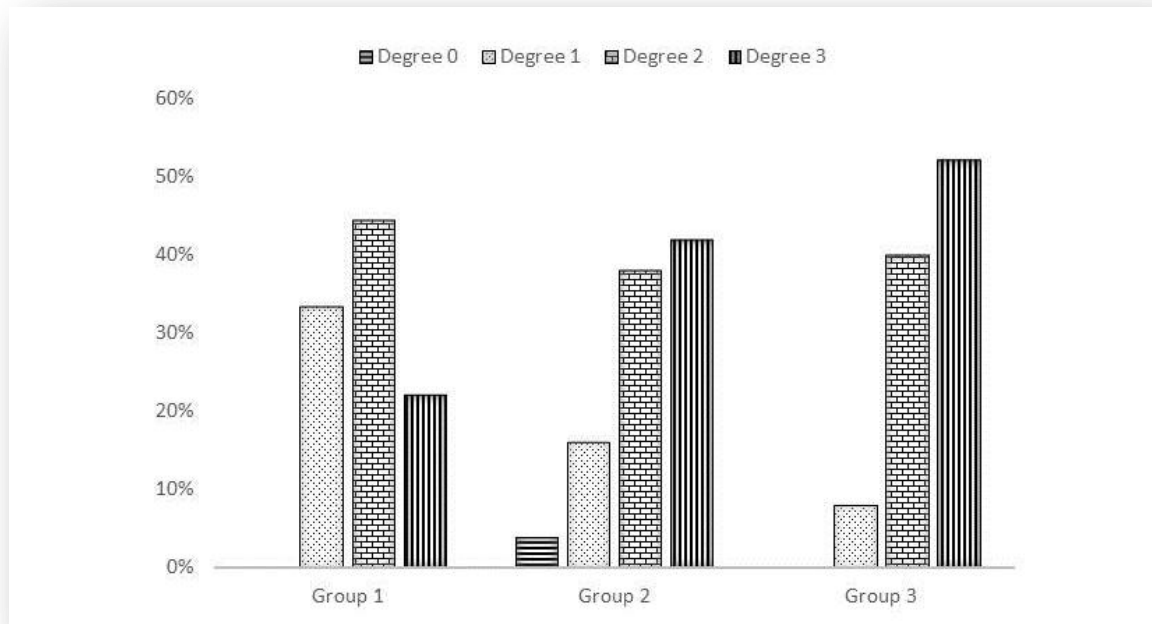
In the period from 2008 to 2012 a total of 587 elbows had been diagnosed with lesion(s) included in the elbow dysplasia complex. The prevalence of medial compartment erosion, diagnosed via arthroscopy, in this study population was 18.1% (n = 106, including cases with incomplete medical records). Of those 106 joints, 84 joints (66 dogs) met the inclusion criteria for this study. Twenty breeds were represented of which the Labrador Retriever (27 dogs, 40.9%) was most common (table 1). Male:female ratio was 1.6:1. Left and right distribution of medial compartment erosion was almost equal (left: 47.6%, 40 elbows and right: 52.4%, 44 elbows) and 18 dogs had bilateral erosion of the medial compartment. The median weight of the dogs was 32.5 kg (range 15 - 60kg). Nine joints (10.7%, 8 dogs) were assigned to Group 1, 50 joints (59.5%, 40 dogs) to Group 2 and 25 joints (29.8%, 19 dogs) to Group 3. One dog was included in both Group 1 and 2 because of a bilateral diagnosis with medial compartment erosion, which was considered a single pathology in one elbow and concomitant in the other elbow. Overall, a significant age difference ( $p < 0.001$ ) between the groups was observed: dogs in Group 1 were significantly older than dogs in Group 2 ( $p < 0.001$ ) and dogs in Group 3 ( $p = 0.025$ ). Dogs in Group 2 were significantly younger than dogs in Group 3 ( $p < 0.001$ ). Median age at diagnosis in Group 1 was 8.5 years (range 6.6 - 11 years), in Group 2 1.8 years (range 0.5 - 10.5 years) and in Group 3 6.9 years (range 0.9 - 9.9 years). Median duration of lameness at the diagnosis of medial compartment erosion was 5 months (range 1 – 78 months). No significant difference ( $p = 0.199$ ) in duration of lameness was found between the three groups.

**Table 1: Breed distribution of 66 dogs with medial compartment erosion.**

<b>Breed</b>	<b>Number of dogs</b>
Labrador Retriever	27 (40.9%)
Cross-breed	7 (10.6%)
German Shepherd Dog	5 (7.6%)
Rottweiler	5 (7.6%)
Bernese Mountain Dog	5 (7.6%)
American Bulldog	2 (3%)
Large Münsterländer	2 (3%)
Single breeds*	13 (19.7%)
Total	66 (100%)

\*One of each: Airdale Terrier, Belgian Malinois, Border Collie, Chow Chow, Dutch Patridge Dog, French Bulldog, Golden Retriever, Greater Swiss Mountain Dog, Scotch Collie, Sheltie, Tibetan Mastiff, Weimaraner and White Swiss Shepherd Dog.

The radiographic degree of osteoarthritis per group is demonstrated in figure 2. No significant difference ( $p = 0.519$ ) was found between the three groups. In general, a high degree of osteoarthritis (degree 2 or 3) was present in 82.1% of the joints (69/84), 15.5% of the joints (13/84) only demonstrated small osteophytes (degree 1) and in 2.4% of the joints (2/84) no osteophytes were present (degree 0). In the 2 joints without osteophytes some sclerosis of the ulnar trochlear notch was noticed.



**Figure 2: Distribution of the radiographic degree of osteoarthritis per group of medial compartment erosion (MCE) (Group 1 = MCE as a single pathology, Group 2 = MCE concomitant to a coronoid pathology and Group 3 = MCE at second-look arthroscopy in dogs with lameness after arthroscopic treatment of medial coronoid disease). Osteoarthritis was scored as 0 = no osteophytes, 1 = osteophytes  $\leq 2$  mm, 2 = osteophytes 2-5 mm and 3 = osteophytes  $> 5$  mm (25).**

A significant difference ( $p < 0.001$ ) in degree of incongruity between the three groups was observed (table 2). The distribution of focal, diffuse and complete pathology of the MHC and the MCP per group is shown in table 3 and 4. There was a significant difference in the extent of the cartilage erosion of the MCP ( $p < 0.001$ ) and the MHC ( $p < 0.001$ ) between groups. Focal erosion was more frequently seen in Group 2, while complete erosion was predominantly seen in Group 1.

**Table 2: Distribution of degree of radioulnar incongruity per group of medial compartment erosion (MCE) (Group 1 = MCE as a single pathology, Group 2 = MCE concomitant to a coronoid pathology and Group 3 = MCE at second-look arthroscopy in dogs with lameness after arthroscopic treatment of medial coronoid disease). Joint incongruity was evaluated during arthroscopic inspection and graded as normal (no radio-ulnar step), mildly (step < 2 mm) or severely (step ≥ 2 mm) incongruent (27).**

	Total amount of joints	Congruent joints	Mildly incongruent joints	Severely incongruent joints
<b>Group 1</b>	9	9 (100%)	0 (0%)	0 (0%)
<b>Group 2</b>	50	13 (26.0%)	24 (48.0%)	13 (26.0%)
<b>Group 3</b>	25	14 (56.0%)	8 (32.0%)	3 (12.0%)

**Table 3: Distribution of the extent of the cartilage pathology of the medial coronoid process (MCP) in joints with medial compartment erosion (MCE). Group 1 = MCE as a single pathology, Group 2 = MCE concomitant to a coronoid pathology and Group 3 = MCE at second-look arthroscopy in dogs with lameness after arthroscopic treatment of medial coronoid disease.**

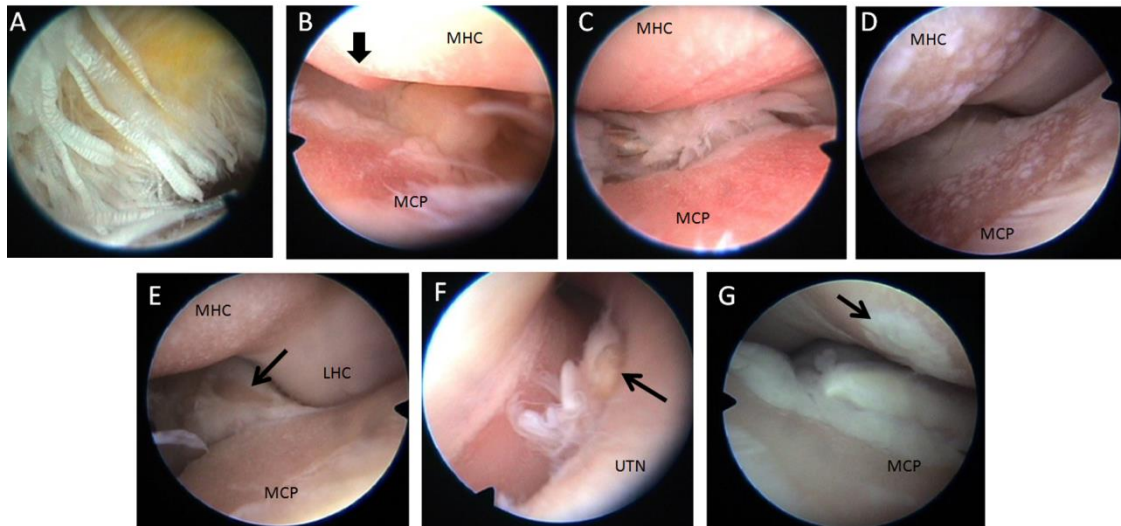
MCP	Focal erosion	Diffuse erosion	Complete erosion
<b>Group 1</b>	0 (0%)	1 (11.1%)	8 (88.9%)
<b>Group 2</b>	30 (60.0%)	13 (26.0%)	7 (14.0%)
<b>Group 3</b>	7 (28.0%)	8 (32.0%)	10 (40.0%)

**Table 4: Distribution of the extent of the cartilage pathology of the medial part of the humeral condyle (MHC) in joints with medial compartment erosion (MCE). Group 1 = MCE as a single pathology, Group 2 = MCE concomitant to a coronoid pathology and Group 3 = MCE at second-look arthroscopy in dogs with lameness after arthroscopic treatment of medial coronoid disease.**

MHC	Focal erosion	Diffuse erosion	Complete erosion
<b>Group 1</b>	0 (0%)	0 (0%)	9 (100%)
<b>Group 2</b>	22 (44.0%)	20 (40.0%)	8 (16.0%)
<b>Group 3</b>	1 (4.0%)	8 (32.0%)	16 (64.0%)

All joints in Group 1 were considered to be congruent on arthroscopic inspection (table 2). The radioulnar congruity of these joints was confirmed by the CT examination in all but one joint.

In Group 2, medial compartment erosion was diagnosed concomitant to various MCP lesions: a displaced fragment of the MCP in 42 joints (84.0%), a non-displaced fragment in 7 joints (14.0%) and a fissure in 1 joint (2.0%). In addition, a loose cartilage flap (OCD) of the MHC was observed in 10 joints and an OCD-like lesion, consisting of fibrocartilaginous tissue attached in a rounded defect on the MHC, was noticed in 2 joints (figure 3). Both OCD and OCD-like lesions were surrounded by an area of full-thickness cartilage loss. In 2 joints, an osteochondral fragment of unknown origin was found additional to an MCP lesion.



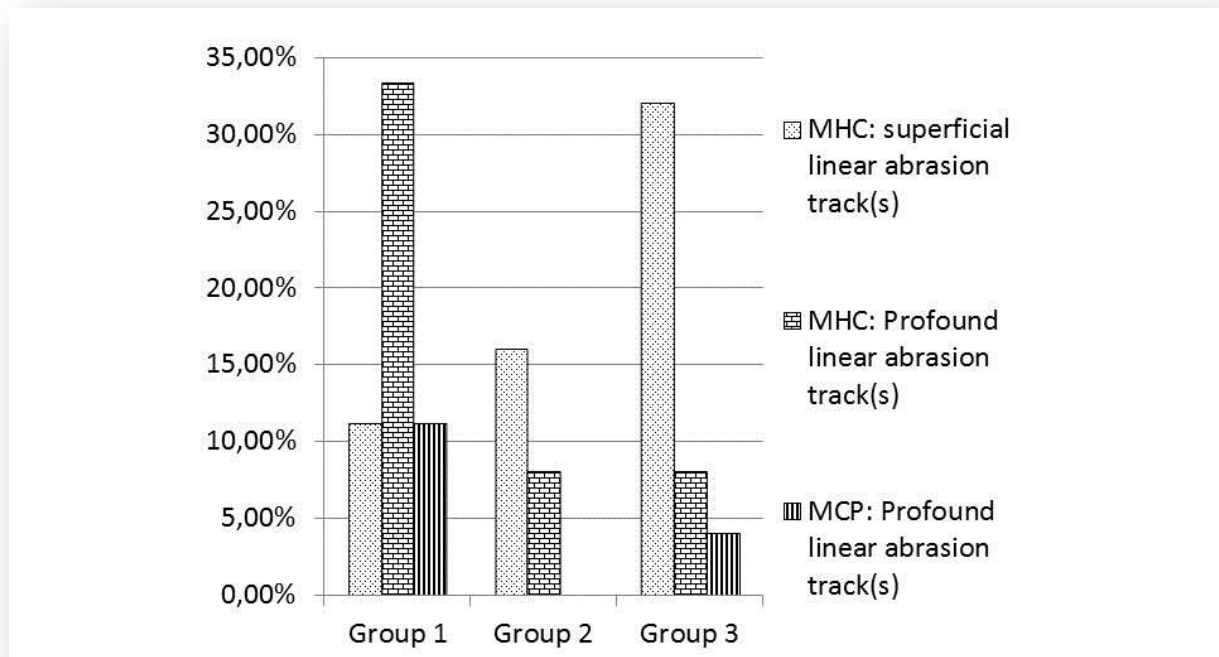
**Figure 3:** Arthroscopic images, obtained via a medial approach (15), of findings in dogs with erosion of the medial elbow compartment (MCP: Medial coronoid process, MHC: Medial part of the humeral condyle, UTN: Ulnar trochlear notch). A: Fibrillated enthesis and yellow discoloration of the flexor muscles. B: A profound linear abrasion track in the subchondral bone of the MHC (arrow). C: Superficial linear abrasion tracks on the MHC. D: White areas in the eroded medial joint compartment. E: Full-thickness cartilage lesion of the medial part of the radial head (arrow). F: Cartilage damage of the lateral part of the humeral condyle (LHC) concomitant to the presence of an osteochondral fragment of unknown origin (arrow). G: OCD-like lesion (arrow) on the MHC surrounded by an area of full-thickness cartilage loss.

Group 3 consisted of 25 joints of dogs presented with lameness after arthroscopic treatment of medial coronoid disease, of which 11 joints (44.0%) demonstrated concomitant loose scar tissue, 5 joints (20.0%) attached scar tissue and 5 joints (20.0%) a calcified body at the level of the MCP. In the remaining 4 joints (16.0%) medial compartment erosion was the only pathology found in the medial joint compartment. All these joints had been treated for disease of the MCP (chondromalacia (n = 4), fissure (n = 10), non-displaced fragment (n = 6), displaced fragment (n = 5)), of which 4 joints were treated for OCD of the MHC as well. During the first arthroscopy, 14 joints (56.0%) demonstrated normal cartilage, except for the MCP lesion or OCD of the MHC, 8 joints (32.0%) demonstrated mild cartilage damage (modified Outerbridge grade 1-2) and 3 joints (12.0%) already showed moderate cartilage damage (modified Outerbridge 3). The average time between the first and second arthroscopic inspection was 3.3 years (range 0.3 – 6.8 years). The median duration of lameness before the second-look arthroscopy was 5 months (range 2 – 78 months).

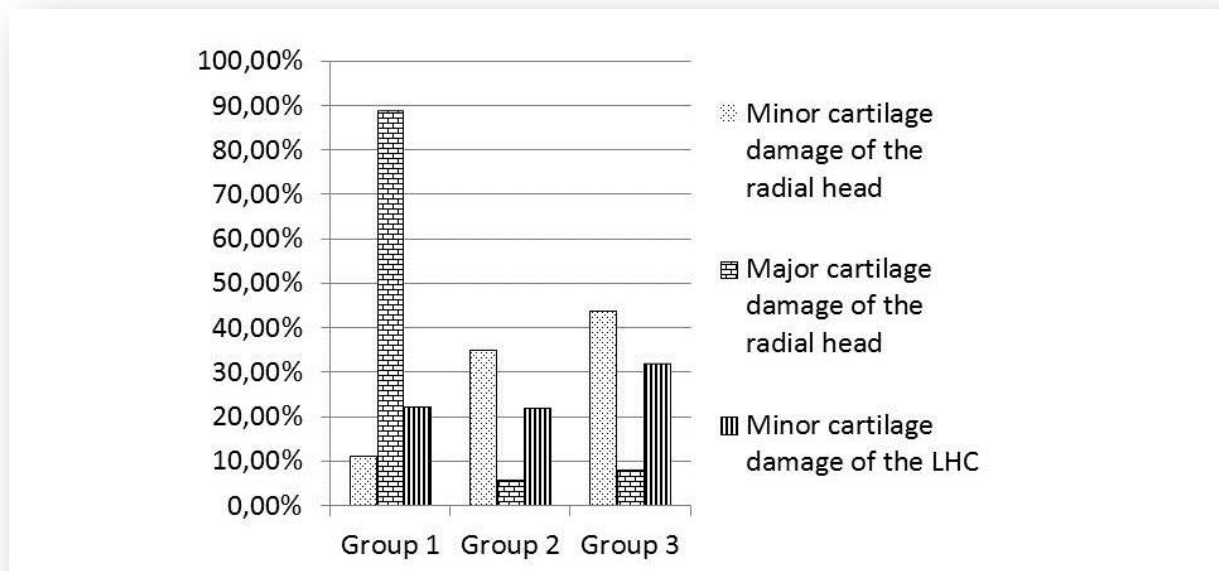
The occurrence of superficial and profound linear abrasion tracks in the subchondral bone of the MCP and the MHC is illustrated in figure 4. In general, linear abrasion tracks in the subchondral bone were observed in joints with diffuse or complete erosions leading to bone-to-bone contact between the MHC and the MCP. No significant difference ( $p = 0.073$ ) was found between groups in the presence of linear abrasion tracks on the MCP. However, a

significant difference was found in the difference of linear abrasion tracks on the MHC ( $p = 0.033$ ). Linear abrasion tracks on the MHC were most commonly found in Group 1 (66.7% of the joints), and were least found in Group 2 (24.0% of the joints). In 10 joints (11.9%) multiple white areas were noticed in the eroded part of the MCP and/or MHC (figure 3). No significant difference ( $p = 0.071$ ) was found between the groups in the presence of these areas. Additional cartilage pathology of the lateral joint compartment (radial head and/or lateral part of the humeral condyle) was recognized in 49 joints (58.3%). Both the radial head and the lateral part of the humeral condyle demonstrated cartilage damage in 14 joints (16.7%). The distribution and severity of pathology of the radial head and lateral part of the humeral condyle are illustrated in figure 5. A significant difference ( $p = 0.012$ ) was found between groups in the presence of damage of the lateral joint compartment. Some damage of the lateral compartment was identified in all joints in Group 1, in 48% of the joints of Group 2 and in 64% of the joints of Group 3. In general, the only visible damage of the radial head was limited to its medial part (figure 3). All joints with a complete erosion of the MHC still showed a sharp demarcation with the cartilage of the lateral joint compartment, even when some cartilage damage of the lateral part of the humeral condyle was observed.

Abnormalities at the enthesis of the flexor muscles, consisting of a fibrillated enthesis of the flexor muscles to the medial humeral epicondyle, a thickening of the flexor muscles or yellow discoloration of the flexor muscles, were detected in 25 joints (29.8%) (figure 3).



**Figure 4:** Prevalence of linear abrasion tracks in the subchondral bone of the medial part of the humeral condyle (MHC) and the medial coronoid process (MCP) in joints with medial compartment erosion (MCE). Group 1 = MCE as a single pathology, Group 2 = MCE concomitant to a coronoid pathology and Group 3 = MCE at second-look arthroscopy in dogs with lameness after arthroscopic treatment of medial coronoid disease.



**Figure 5:** Prevalence of major (modified Outerbridge grade 4-5) and minor (modified Outerbridge grade 1-3) cartilage damage of the radial head and the lateral part of the humeral condyle (LHC) in joints with medial compartment erosion (MCE). Group 1 = MCE as a single pathology, Group 2 = MCE concomitant to a coronoid pathology and Group 3 = MCE at second-look arthroscopy in dogs with lameness after arthroscopic treatment of medial coronoid disease.

## **Discussion**

Medial compartment erosion, an advanced stage of medial coronoid disease, has gained more interest and several specific treatment techniques have been developed to address this debilitating disease of the canine elbow joint. Joints with medial compartment erosion can be divided into three groups: medial compartment erosion as a single finding (Group 1), concomitant with a fragmented/fissured MCP and/or OCD of the MHC (Group 2), and as a finding during second-look arthroscopy in dogs with lameness after arthroscopic treatment of medial coronoid disease (Group 3) (10, 11, 13, 18, 19). Limited information is available on the prevalence of the three specific groups of medial compartment erosion and their characteristics. This study demonstrated significant differences in age, joint incongruity, extent of the cartilage lesions, damage in the lateral joint compartment and presence of linear abrasion tracks on the MHC between the three groups of medial compartment erosion and illustrated that several additional pathologies can occur in these joints.

The high number of Labrador Retrievers in this study is prominent. Other studies reporting on treatment techniques for medial compartment erosion also mention a high frequency of Labrador Retrievers (9, 24). Possibly, this breed is more vulnerable to cartilage degeneration. More likely, this high number of Labrador Retrievers affected with medial compartment erosion can be explained by the popularity and the high prevalence of elbow dysplasia in general within this breed (1, 16, 29).

Dogs in Group 1 were significantly older than dogs in the other two groups and had a minimum age of 6.6 years old. This finding is in contrast with other studies that reported medial compartment erosion as a single finding in younger dogs as well (10, 30). Possibly, subtle concomitant pathology of the MCP or MHC may have been overlooked in these younger dogs. Next to the older age of the dogs, complete erosion of the medial compartment was most frequently seen in joints in Group 1. This finding is consistent with the conclusion of a study on Labrador Retrievers with disease of the MCP reporting a significant relationship between age and the global cartilage pathology (31).

The radiographic degree of osteoarthritis was high in the majority of the joints. This could be expected since it is known that there is a correlation between the radiographic degree of osteoarthritis and articular cartilage damage in the medial elbow compartment (1, 10, 31). However, 2 joints diagnosed with medial compartment erosion demonstrated no osteophytes.

A similar finding has been reported by Vermote et al. (10). Therefore, the diagnosis of medial compartment erosion cannot be excluded based on radiographic examination only.

The etiology of erosion of the medial elbow compartment has not been clarified yet. A common pathway between disease of the MCP and medial compartment erosion has been suggested (1). Radioulnar incongruity may generate supraphysiological overload of the medial joint compartment (4-7). However, in our study several joints with medial compartment erosion were considered congruent based on arthroscopic joint inspection. Possibly, incongruity was only temporary present during skeletal growth (3), or joint congruity was misinterpreted during arthroscopy. Although arthroscopy has been described to be an appropriate technique for the diagnosis of radioulnar incongruity (5, 27), it is known that insertion of the arthroscope and/or the non-weight bearing position of the leg can influence interpretation of joint incongruity (32). Nevertheless, the remarkable finding of all joints in Group 1 being congruent on arthroscopy could be confirmed by CT examination in all but one joint. Therefore, it is possible that other factors may be involved in the development of medial compartment erosion, especially when it is presented as a single finding.

In this study, medial compartment erosion was most often identified concomitant with a MCP lesion (Group 2). A displaced fragment of the MCP was the predominant concomitant finding in this group. Conflict between the intact portion of the MCP and the MHC and/or chronic inflammation created by the presence of a fragment might have caused the development of medial compartment erosion (3, 33). Linear abrasion tracks in the subchondral bone were least found in this group. Those linear abrasion tracks, possibly caused by profound humeroulnar conflict, were most observed in joints with diffuse or complete erosions leading to bone-to-bone contact between the MHC and the MCP. Since focal erosion was most frequently observed in Group 2, this could explain the lower occurrence of linear abrasion tracks in this group.

Erosion of the medial compartment in dogs with lameness after arthroscopic treatment of disease of the MCP was the second largest group in this study. It has been suggested that fragmentation of the MCP is a first step of medial coronoid disease before erosion of the more resilient part of the MCP occurs (1). Indeed, the first arthroscopic treatment of these joints only consisted of fragment removal, making further supraphysiological loading of the remaining part of the MCP possible. However, more than half of the joints of Group 3 were



considered congruent joints. Although elbow congruency is challenging to assess, it is likely that other factors or other unknown underlying conditions are involved in the etiopathogenesis of these severe cartilage erosions. For example, it is possible that the initial surgical intervention, interrupting the joint surface, triggered the progression of degenerative cartilage damage (19).

Information on the prevalence of pathology of the lateral elbow compartment in joints with erosion of the medial compartment is scarce in the literature, since medial compartment erosion only relates to cartilage damage of the MHC and the corresponding ulnar contact area (9-11). In general it is stated that pathology of the lateral compartment is less common (1). This study identified cartilage damage of the radial head and/or the lateral part of the humeral condyle in more than half of the joints with medial compartment erosion, of which minor damage (modified Outerbridge grade 1-3) of the radial head was the most frequent finding. *In vitro* studies demonstrated that the proximal articular surfaces of the radius and the ulna contribute almost equally to load transfer through the elbow joint (34, 35). The radial contact area is located on the caudomedial aspect of the radial articular surface, with its longest dimension oriented mediolaterally (34). In our study, damage of the radial articular surface was only observed in the medial part of this area (figure 3). Possibly, only the part of the radial head that corresponds with the eroded MHC displays cartilage loss. Therefore detailed inspection of the radial articular surface is recommended during arthroscopic joint inspection and additional damage of the radial head should be taken into account before specific treatment methods for medial compartment erosion, such as a unicompartamental elbow arthroplasty or a sliding humeral osteotomy, are considered (9, 22).

In 10 joints (11.9%) multiple white areas were noticed within the eroded part of the MCP and/or MHC. These might be areas of fibrocartilaginous repair tissue. However, due to the retrospective nature of this study, histopathological examination of these lesions were not performed. Thus, it cannot be excluded that these areas are resilient parts of articular cartilage.

Abnormalities at the enthesis of the flexor muscles were detected in almost one third of the joints. It is known that arthroscopy often reveals abnormalities at the enthesis of the flexor muscles in joints with elbow dysplasia lesions (36). The clinical relevance of these findings is unclear.

In veterinary medicine, the modified Outerbridge classification system is considered the 'gold standard' for arthroscopic evaluation of cartilage lesions (1, 31). However, this grading

system only takes into account the depth of the cartilage lesion, without considering the extent of the lesion. A recent study evaluated the global articular cartilage damage in Labrador Retrievers using a composite cartilage score (CCS) which accounted for lesion depth, location and surface area (31). However, this CCS system was not suitable for our study, since nearly all joints with modified Outerbridge grade 4 and 5 (= medial compartment erosion) would have been classified in the highest category being 'severe disease'. Therefore we proposed a new classification scheme, using the terms focal, diffuse and complete, to determine the extent of the cartilage lesions in joints with medial compartment erosion. A limitation of this classification is that it is rather subjective and not quantitative, since our data were collected retrospectively. The use of the proposed grading scheme allows a classification that may be useful to decide on the type of therapeutic approach as well in the future.

In conclusion, this study provides an overview of the arthroscopic findings in three types of MCE. Significant differences in age, radioulnar incongruity, extent of the cartilage lesions, damage in the lateral compartment and presence of linear abrasion tracks on the MHC were identified between the three groups. These findings may contribute to the determination of underlying pathophysiological characteristics that lead to medial compartment erosion. In addition, this study illustrated several additional pathologies that can occur in joints with erosion of the medial compartment, including cartilage damage of the lateral joint compartment, flexor enthesopathy and /or a fragment, a calcified body or loose scar tissue at the level of the MCP. These additional pathologies should not be overlooked when medial compartment erosion is diagnosed and should be taken into account when treatment-decisions are made.

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### **Chapter 3**

**Computed tomographic findings in 56 canine elbows  
arthroscopically diagnosed with erosion of the medial  
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### **Summary**

The aim of this retrospective study was to describe the CT findings in elbows of dogs diagnosed with medial compartment erosion. The identification of specific CT findings might facilitate the non-surgical diagnosis and add to treatment decision-making. Retrospectively, CT findings in 56 elbows were evaluated and compared in elbows with focal ( $n = 13$ ), diffuse ( $n = 11$ ) and complete ( $n = 32$ ) erosion.

The most prevalent CT signs in these 56 elbows were periarticular osteophytosis (100%), an abnormal shape of the medial coronoid process of the ulna (MCP) (96.4%) and a subchondral bone defect of the medial part of the humeral condyle (MHC) (96.4%). The 3 groups differed significantly in terms of presence of fragmentation of the MCP, radial head subchondral bone sclerosis and widening of the humeroulnar joint space. When comparing CT and arthroscopy, no significant agreement was found between the observation of a subchondral bone defect of the MHC on CT and the lesion of the MHC found on arthroscopy. A significant agreement was found between CT and arthroscopy for the detection of fragmentation of the MCP. However, some of the calcified body/fragment(s) visualized on CT in the MCP region could not be identified via arthroscopy.

Distinguishing focal, diffuse and complete erosion on CT examination remains difficult, despite the identification of 3 significantly different findings. An accurate estimation of the extent of the cartilage lesions still requires arthroscopic joint inspection.

## **Introduction**

Medial coronoid disease, part of the elbow dysplasia complex, is a common cause of thoracic limb lameness in medium to large breed dogs (1, 2). Medial coronoid disease includes fissuring and fragmentation of the medial coronoid process of the ulna (MCP) combined with a varying degree of cartilage pathology (1-3). An advanced stage of this disease is erosion of the medial elbow compartment, referring to full-thickness cartilage loss (modified Outerbridge grade 4-5) of the medial part of the humeral condyle (MHC) and the corresponding ulnar contact area (4, 5). The modified Outerbridge grading system is used to score articular cartilage damage. Grade 4 describes full-thickness cartilage loss with exposure of the subchondral bone and grade 5 refers to eburnated bone (3, 4). This cartilage pathology of the medial joint compartment can be limited to a small area (focal erosion), or can comprise the entire cartilage surface of the MCP and the MHC (diffuse erosion) and sometimes even extend to the ulnar trochlear notch (complete erosion) (5, 6). The etiopathogenesis of this disease is not yet fully understood, but radioulnar incongruity is believed to be an important factor in the development of medial coronoid disease and medial compartment erosion because of chronic supraphysiologic loading of the medial joint compartment (7, 8).

Medial compartment erosion is not only reported as a concomitant finding with MCP pathology or osteochondritis dissecans of the MHC or both, it can also be diagnosed as a single pathology or as a finding during second-look arthroscopy in dogs with persistent or recurrent lameness after initial arthroscopic treatment of medial coronoid disease (4, 9-12).

CT is a sensitive technique to diagnose fragmentation or fissuring of the MCP since it shows good bone detail (13-15). However, cartilage cannot be visualized via plain CT and therefore the absence of CT signs of fissuring or fragmentation of the MCP does not rule out elbow pathology (13). Cartilage pathology can be suspected on CT examination of the elbow since CT osteophyte size is moderately correlated with cartilage erosion of the medial elbow compartment (13). Nevertheless, there is need for more sensitive diagnostic methods to identify cartilage lesions in the canine elbow because of the high incidence of cases with no significant abnormalities on radiographic and CT examination (16).

Arthroscopy is considered the gold standard technique for the evaluation of cartilage lesions and is the only reliable technique to accurately diagnose erosion of the medial elbow joint compartment (4, 9, 17, 18).

Treatment of medial compartment erosion is challenging and the prognosis is usually guarded (4). The applied treatment technique and the expected prognosis depend on the extent of the cartilage lesions. In all cases with a concomitant fragment or calcified body, arthroscopic fragment removal is advised (4). In addition to the arthroscopic treatment, a proximal ulnar osteotomy can be applied to treat focal cartilage lesions (19). More extensive (diffuse or complete) erosion of the medial compartment, can be treated with more invasive surgical procedures such as a sliding humeral osteotomy or a unicompartmental elbow arthroplasty (5, 20,21). The presence of normal articular cartilage in the lateral joint compartment is required before considering treatment via these latter surgical procedures (5, 20). In elbow joints with erosions in the lateral compartment as well, a total elbow replacement can be considered (4). Earlier detection of erosion of the medial elbow compartment in the diagnostic process by means of noninvasive imaging techniques and the ability to determine the extent of the cartilage erosion before surgery would add to treatment-decision making in these advanced cases and might facilitate surgical planning.

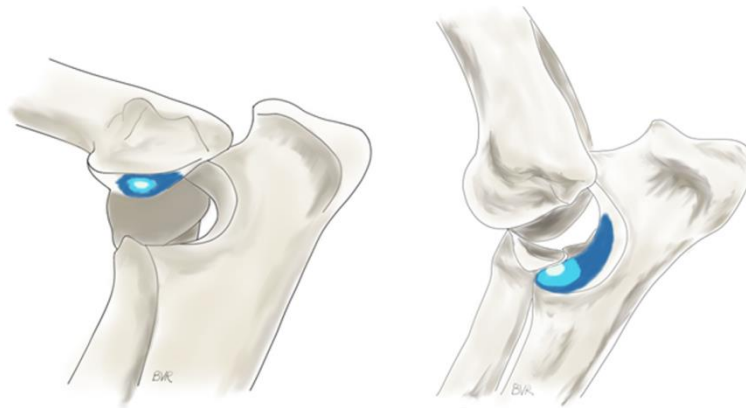
The first aim of this study was to evaluate CT findings in elbows with arthroscopically confirmed medial compartment erosion and compare these findings in joints with focal, diffuse and complete erosion. The second aim was to evaluate the agreement between the CT findings and the arthroscopic findings in these elbow joints with medial compartment erosion.

## **Materials and methods**

The study was performed retrospectively and contains an analytical part (first aim) and a method comparison study (second aim). Medical records (2008-2014) from the authors' institution, were searched for dogs investigated with elbow CT and arthroscopically diagnosed with erosion of the medial joint compartment. Inclusion criteria were the availability of the original CT Digital Imaging and Communications in Medicine standard (DICOM) file obtained via the standard CT image acquisition protocol used in our hospital (as described below) and a complete report, and still and video images of the arthroscopic procedure. A complete report of the arthroscopic procedure comprised information on the pathology of the medial coronoid process, a modified Outerbridge classification of the medial coronoid process and the medial part of the humeral condyle, information on the presence of subchondral bone defect(s) of the medial part of the humeral condyle and the presence of a radioulnar step. All elbows meeting the inclusion criteria during the time period of 2008 to 2014 were included when the diagnosis of medial compartment erosion could be confirmed by a faculty surgeon, with over 20 years of experience in small animal arthroscopy (BVR), based on the available arthroscopic report and images.

Arthroscopy was performed via a medial approach, using a 1.9 or a 2.4 arthroscope (Richard Wolf, Knittlingen, Germany) (17). All arthroscopies were performed by experienced faculty surgeons. Standard still and video images were obtained during the procedure, visualizing the medial coronoid process, the medial and lateral part of the humeral condyle, the radial head and the ulnar trochlear notch, and an arthroscopic report was completed at the end of the surgery. Only elbows with modified Outerbridge grade 4 or 5 cartilage lesions of the MHC and the MCP were included. Pathology of the MCP was registered as: A fissure, a non-displaced fragment or a displaced fragment. Not only was the depth of the cartilage lesions evaluated, using the modified Outerbridge classification (4), but also the extent of the lesion was graded retrospectively by the first author together with an experienced faculty surgeon (BVR), based on the arthroscopic report, and the still and video images. The extent of the erosions was graded as focal, diffuse or complete (Figure 1) (6). Elbows were divided into 3 groups: Group F includes the elbows with only focal erosion of the MCP and MHC, group D elbows with diffuse erosion and group C elbows with complete erosion. Focal erosions are very localized full-thickness cartilage erosions limited to the most medial aspect of the MCP and the corresponding contact area on the MHC. Diffuse erosions affect the majority of the

cartilage surface of the MCP and the corresponding area on the MHC. However the cartilage of the trochlear notch and the corresponding humeral cartilage is still intact. Complete erosions affect the entire surface of the MHC and the MCP including the cartilage of the ulnar trochlear notch and the corresponding humeral cartilage. The presence of subchondral bone defects of the MHC was registered. Radioulnar joint incongruity was evaluated as well and graded as congruent (no step), mildly incongruent (step < 2 mm) or severely incongruent (step  $\geq$  2 mm) using a hooked probe.



**Figure 1:** Schematic representation of the extent of the cartilage erosion on the MHC (left) and the MCP (right) illustrating the three different presentations of medial compartment erosion. Focal erosions are very localized full-thickness cartilage erosions (white area). Diffuse erosions affect the majority of the cartilage surface of the MCP and the MHC (light blue area) but the cartilage of the trochlear notch or the corresponding humeral cartilage is still intact. Complete erosions affect the entire surface of the MHC and the MCP including the cartilage of the ulnar trochlear notch and the corresponding humeral cartilage (dark blue area).

To perform the CT scan, the dogs were anesthetized and positioned on the CT table in lateral recumbency with the elbow joints parallel and extended cranially. A wedge was positioned between the elbow joints in order to make them parallel to each other. Both elbows were always scanned at the same time. The head of the dogs was pulled back laterally to scan only the elbow joints in the gantry and avoid beam hardening artifacts (22). CT scans were performed with a 4-slice helical CT device (CT-scanner, LightSpeed, GE Medical Systems, Milwaukee, WI) at 120 kV and 140 mA and a pitch of 0.75, using a bone algorithm (WL 500, WW 3000). Transverse images with slice thickness of 1.25 mm with 0.6 mm overlap in helical acquisition were obtained from the most proximal part of the ulna to 3 cm distal to the radial head.

The DICOM studies were retrieved and analyzed on a computer workstation using image analysis software (Merge Efilm, Merge eMed, Milwaukee, WI). Transverse slices were first assessed. Subsequently, multiplanar reconstructions were made to obtain sagittal and dorsal

plane projections. Two medical imaging specialists (a board-certified radiologist (HvB) and the head of the CT/MRI department with 20 years of experience (IG)) together reviewed in a random order each series, unaware of the arthroscopic findings and the prior CT report. To evaluate CT-images, a list of predetermined variables was inspected and a joined consensus was reached for their presence/absence (Table 1).

Maximal osteophyte size was recorded using a four point scale (absent, less than 2 mm, 2 to 5 mm and greater than 5 mm) (23). If present, the size and the displacement of the fragmented part of the MCP were registered. A displaced fragment of the MCP was diagnosed when a calcified structure was observed that appeared separate to the adjacent bones. A non-displaced fragment was diagnosed when a lucent line was observed, dividing the MCP. CT is not able to make the differentiation between a non-displaced fragment and a fissure of the MCP since this requires arthroscopic probing of the lesion (9). Therefore, both lesions are named non-displaced fragments on CT. Presence of an abnormal shape of the MCP, lucency within the MCP, osseous cyst-like lesions and irregularity of the radial incisure, flattening of the MHC, subchondral bone sclerosis of the MCP, ulnar trochlear notch, radial head, MHC and the lateral part of the humeral condyle were assessed subjectively, and compared to CT images of normal canine elbows. Subchondral bone sclerosis was only registered as 'present' if it was prominently visible. Defects in the subchondral bone of the MHC were subjectively classified as a rounded lucent defect, a single linear lucent defect or multiple linear lucent defects on transverse images. On the reconstructed dorsal images these defects were visible as single or multiple indentation(s) or lucent area(s) in the MHC. Defects in the subchondral bone of the lateral part of the humeral condyle were recorded as well. The humeroulnar joint space was evaluated on transverse and sagittal images and considered widened when there was an obvious lack of congruity between the ulna and the humeral condyle (24). The radioulnar joint space width was evaluated on transverse images (24). Presence of a radioulnar step was evaluated and measured on dorsal and sagittal reconstruction images (24). An abnormal appearance of the attachment of the flexor muscles on the medial humeral epicondyle (= irregular delineation, sclerotic or thickened cortex), presence of a calcified body at the level of the medial humeral epicondyle and thickening of the flexor muscles were registered (25).



**Table 1: CT signs observed in 56 elbows arthroscopically diagnosed with erosion of the medial compartment.**

CT sign	Arthroscopic findings		
	Focal erosions (n= 13) n (%)	Diffuse erosions (n= 11) n (%)	Complete erosion (n= 32) n (%)
<b>Largest osteophyte (mm)</b>			
< 2	2 (15)	0 (0)	6 (19)
2 to 5	8 (62)	6 (55)	17 (53)
> 5	3 (23)	5 (45)	9 (28)
<b>Medial coronoid process</b>			
Fragmentation*	13 (100)	5 (45)	20 (63)
Subchondral bone sclerosis	12 (92)	10 (91)	26 (81)
Lucency	9 (69)	6 (55)	26 (81)
Abnormal shape	13 (100)	11 (100)	30 (94)
Irregular radial incisure	9 (69)	9 (82)	23 (72)
<b>Ulna</b>			
Subchondral bone sclerosis	11 (85)	9 (82)	30 (94)
Osseous cyst-like lesions	11 (85)	9 (82)	24 (75)
<b>Medial part of the humeral condyle</b>			
Subchondral bone sclerosis	12 (92)	11 (100)	30 (94)
Flattening	10 (77)	10 (91)	28 (88)
Rounded subchondral defect (OCD)	5 (38)	0 (0)	5 (16)
Single linear subchondral defect	3 (23)	5 (45)	7 (22)
Multiple linear subchondral defects	4 (31)	6 (55)	19 (59)
Osseous cyst-like lesions	6 (46)	7 (64)	21 (66)
<b>Lateral part of the humeral condyle</b>			
Subchondral bone sclerosis	2 (15)	3 (27)	13 (41)
Subchondral defect	1 (8)	1 (9)	7 (22)
<b>Radial head</b>			
Subchondral bone sclerosis*	0 (0)	0 (0)	11 (34)
<b>Medial humeral epicondyle</b>			
Abnormal appearance	8 (62)	10 (91)	22 (69)
Thickened flexor muscles	3 (23)	6 (55)	7 (22)
Calcified body	0 (0)	1 (9)	5 (16)
<b>Joints spaces/ incongruity</b>			
Widened humeroulnar joint space*	12 (92)	11 (100)	17 (53)
Widened radioulnar joint space	9 (69)	9 (82)	19 (59)
Radioulnar step	8 (62)	4 (36)	8(25)

\*Significantly different variables between the three groups.

The statistical analysis was divided in two parts. Firstly, it was assessed whether there was an effect of the type of erosion (focal, diffuse or complete) on the various variables using (linear or logistic) mixed models with animal as random effect. Radioulnar step size was measured

on both sagittal and dorsal reconstruction images, so for this variable a principal component analysis was conducted first. The first principal component (PCA1) explained > 95% of the variation. The scores according to this PCA1 were used as a dependent variable to evaluate the effect of the extent of the erosion in a linear model. Significance of the fixed effect was assessed with likelihood ratio tests. Due to quasi-separation, not all variables could be evaluated using mixed model. For these variables (i.e. MCP fragmentation, abnormal shape of the MCP, subchondral bone sclerosis of the MCP and of the radial head, rounded subchondral defect of the MHC, calcified body at the medial humeral epicondyle and widening of the humeroulnar joint space) a Fisher exact test with 10 000 simulations was used to evaluate significance. For each of these variables, the Fisher exact test was run twice to assess the potential effect of animal dependency: once for the entire group of elbows ( $n = 56$ ), once in the subgroup of unilateral dogs ( $n = 44$ ) and the outcome of both tests is reported. Both Fisher exact tests always agreed throughout the study.

In the second part, the intermethod agreement between CT and arthroscopy was evaluated. The overall agreement was calculated, together with Cohen's kappa.

The statistical analysis was conducted with R (version 3.3.1, "Bug in your hair") with the lme4-package (26). Significance was set at  $P < 0.05$ .

## **Results**

### ***Dogs***

Fifty-six (26 right, 30 left) elbows of 49 dogs were included in this study. Breeds represented were Labrador Retriever (n = 21), crossbreed (n = 6), Bernese Mountain Dog (n = 3), Rottweiler (n = 3), German Shepherd Dog (n = 2), Swiss White Shepherd Dog (n = 2), Dutch Patridge Dog (n = 2), Airdale Terrier (n = 1), American Bulldog (n = 1), Chow Chow (n = 1), French Bulldog (n = 1), Golden Retriever (n = 1), Large Münsterländer (n = 1), Scottish Collie (n = 1), Shetland Sheepdog (n = 1), Small Münsterländer (n = 1), Weimaraner (n = 1). Thirty-two dogs were male (29 intact, 3 neutered) and 17 female (15 intact, 2 spayed). Median age of the dogs was 6 years and 5 months (range 7 months to 11 years). Based on arthroscopic joint inspection these 56 elbows could be subdivided into 3 groups based on the extent of the erosion of the medial joint compartment (Table 2).

**Table 2: Age and gender of 49 dogs with one or both elbow(s) arthroscopically diagnosed with focal, diffuse or complete medial compartment erosion.**

	Amount of dogs	Median age	Gender		Affected elbow	
			Male	Female	Left	Right
<b>Focal erosion</b>	12	11 months	8	4	7	6
<b>Diffuse erosion</b>	9	6 years 11 months	6	3	7	4
<b>Complete erosion</b>	28	7 years	18	10	16	16

### ***Arthroscopic findings***

Thirteen elbows (23.2%) were arthroscopically diagnosed with focal erosion (group F), 11 elbows (19.6%) with diffuse erosion (group D) and 32 elbows (57.2%) had complete erosion (group C) of the medial compartment. Arthroscopy demonstrated the absence of concomitant MCP fragmentation in 12 elbows (21.4%), the presence of a concomitant displaced fragment of the MCP in 23 elbows (41.1%), a non-displaced fragment in 1 elbow (1.8%) and multiple fragments (displaced and non-displaced) in 1 elbow (1.8%). Nineteen elbows (33.9%) were diagnosed with medial compartment erosion during a second-look arthroscopy after earlier treatment of medial coronoid disease without erosion of the medial joint compartment. Of those elbows, 7 demonstrated a rounded calcified body and 12 elbows showed loose or immobile scar tissue at the level of the MCP. Lesions found at the MHC are demonstrated in table 3. In 3 joints (5.4%) an additional OCD-like lesion was found, consisting of

fibrocartilaginous tissue attached in a rounded defect on the MHC surrounded by an area of full-thickness cartilage loss. Twenty-nine elbows (51.8%) were considered congruent, 18 mildly incongruent (32.1%) and 9 severely incongruent (16.1%).

**Table 3: Agreement between lesions of the medial part of the humeral condyle found on CT and arthroscopy in 56 elbow joints diagnosed with erosion of the medial compartment.**

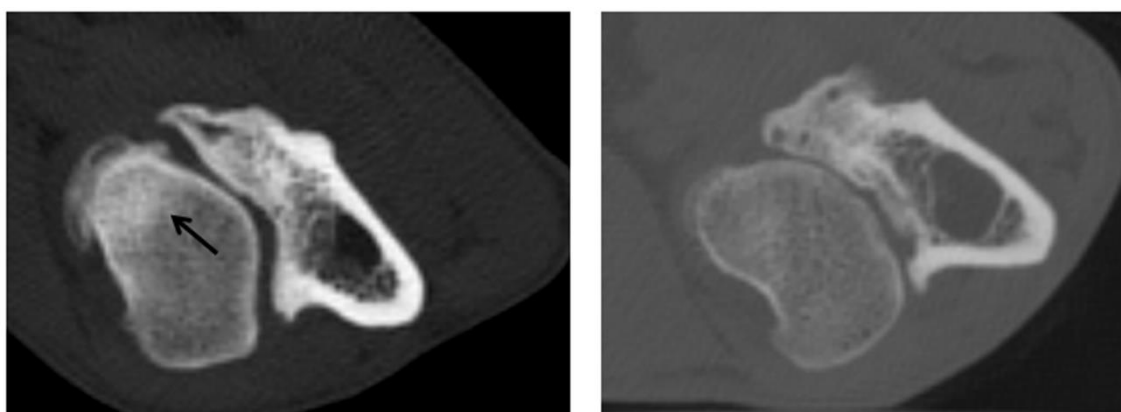
Arthroscopic findings	Amount of joints n (%)	CT findings			
		Rounded subchondral defect (OCD)	Single linear subchondral defect	Multiple linear subchondral defects	No subchondral defect
<b>OCD-like lesion</b>	3 (5.4)	3	0	0	0
<b>Single linear abrasion track</b>	10 (17.8)	1	3	6	0
<b>Multiple linear abrasion tracks</b>	9 (16.1)	1	1	7	0
<b>No subchondral defect (= even cartilage loss)</b>	34 (60.7)	5	11	16	2

### *CT findings*

Overall, the most prevalent CT signs in elbows with medial compartment erosion were periarticular osteophytosis (100%), an abnormal shape of the MCP (96.4%), a subchondral bone defect of the MHC (96.4%), subchondral bone sclerosis of the MHC (94.6%), ulnar trochlear notch (89.3%) and MCP (85.7%) and flattening of the MHC (85.7%). The CT-findings per group are summarized in table 1.

When the findings of group F, D and C were compared, three variables differed significantly. First, a significant difference in presence of fragmentation of the MCP was found ( $p < 0.01$ ,  $p_{\text{subset}} = 0.04$ ). In group F all elbows demonstrated fragmentation of the MCP, while no fragment was observed in 6 (55%) and 12 (37%) of the elbows in group D and C respectively. Secondly, a significant difference in radial head subchondral bone sclerosis was found ( $p < 0.01$ ,  $p_{\text{subset}} = 0.04$ ). In group F and D no subchondral bone sclerosis of the radial head was observed. In group C subchondral bone sclerosis of the radial head was noticed in 11 elbow joints (34%) (Figure 2). The third significantly different variable between the groups was the presence of a widened humeroulnar joint space ( $p < 0.01$ ,  $p_{\text{subset}} < 0.01$ ). All but one joint in

group F and all joints in group D demonstrated a widened humeroulnar joint space, while this was only observed in 17 elbows (53%) of group C. Fragment size observed on CT images varied from 0.8 mm x 0.8 mm to 11.9 mm x 6.0 mm, with a median size of 4.0 mm x 3.0 mm. No significant difference in fragment size between the three groups was found ( $p = 0.64$  (length) and  $p = 0.49$  (width)). CT measurements of the radioulnar step varied from 0 to 5.09 mm on sagittal and dorsal reconstructions. No significant difference was found between the three groups in the principal component that combines the size of the radioulnar step on dorsal and sagittal reconstruction images ( $p = 0.21$ ).



**Figure 2:** Examples of transverse computed tomographic images in a bone window (WL 500, WW 3000) of an elbow with obvious subchondral bone sclerosis of the radial head including the medial aspect (A) and an elbow without obvious radial head subchondral bone sclerosis (B).

### *Comparison between CT and arthroscopic findings*

No significant agreement was found (26.7% agreement,  $\kappa = 0.126$ ) between the observation of a subchondral bone defect of the MHC on CT and the subchondral bone lesion of the MHC found on arthroscopy (table 3). The disagreement between CT and arthroscopic findings seemed to be caused by the remarkable fact that a defect (rounded or linear) was observed on CT in 32 joints (57%) that demonstrated an even cartilage loss on arthroscopy, without obvious subchondral bone defects (Figure 3).

Agreement between arthroscopic identification of fragmentation of the MCP and the CT-findings is shown in table 4. A significant agreement (69.6% agreement,  $\kappa = 0.478$ ) was found between fragmentation of the MCP on CT and finding a fragment or calcified body on arthroscopy. The calcified body found during second-look arthroscopy in 7 elbows was rounded and on CT it was located more cranially compared to a typical displaced fragment of the MCP (Figure 4). Aside from the blunt shape of the MCP, because of the previous treatment, no corresponding subchondral defect was recognized in these cases. Despite the

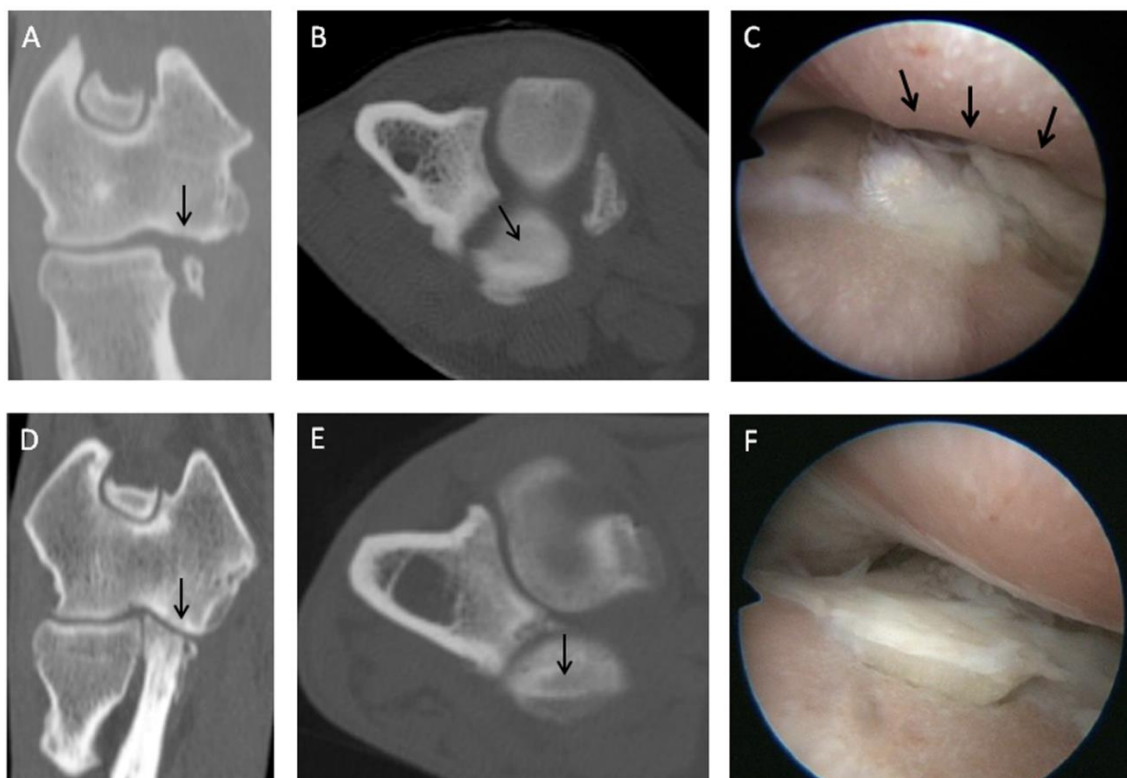
significant agreement between CT and arthroscopy, the calcified body/fragment(s) visualized on CT could not be identified during arthroscopic joint inspection in 10 joints (table 4) (Figure 5). Eight out of 10 of these joints were second-look arthroscopies.

The agreement between the presence or absence of a radioulnar step on CT and arthroscopy was low (62.5% agreement,  $\kappa = 0.242$ ). Twenty-two elbow joints were considered congruent on both CT and arthroscopy and in 13 elbow joints a radioulnar step was identified with both techniques. On the other hand, CT identified a radioulnar step in 10 elbow joints when arthroscopy did not, and arthroscopy visualized a radioulnar step in 11 elbow joints when CT did not.

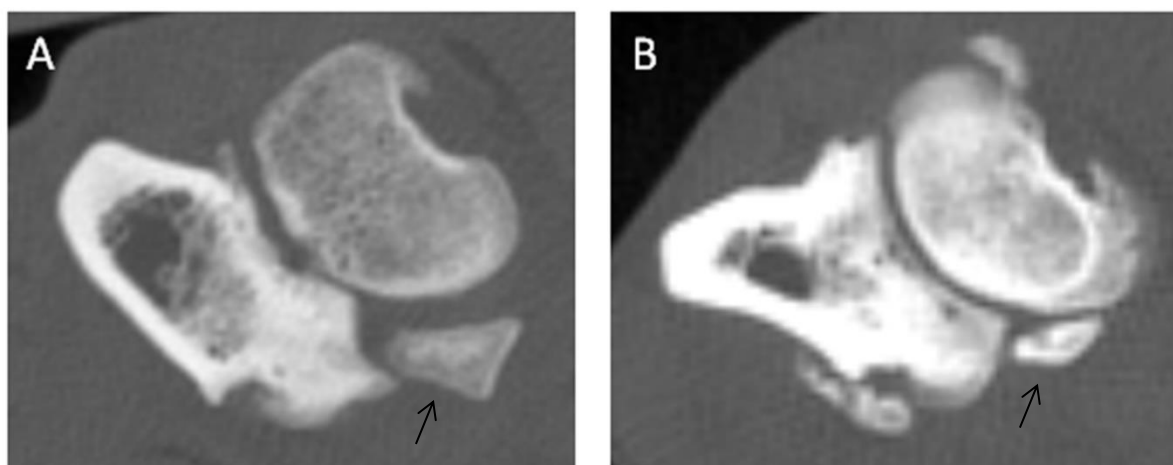
**Table 4: Agreement between the pathology of the medial coronoid process on computed tomography (CT) and arthroscopy in 56 elbow joints diagnosed with erosion of the medial compartment.**

Arthroscopic findings	Amount of joints n (%)	CT-findings			
		No fragmentation	Non-displaced fragment	Displaced fragment	Multiple fragments (displaced/non-displaced)
No fragmentation (incl. scar tissue*)	24 (42.8)	14	2	6	2
Fissure/Non-displaced fragment	1 (1.8)	0	1	0	0
Displaced fragment (incl. calcified body*)	30 (53.6)	4	1	23	2
Multiple fragments (displaced/non-displaced)	1 (1.8)	0	0	0	1

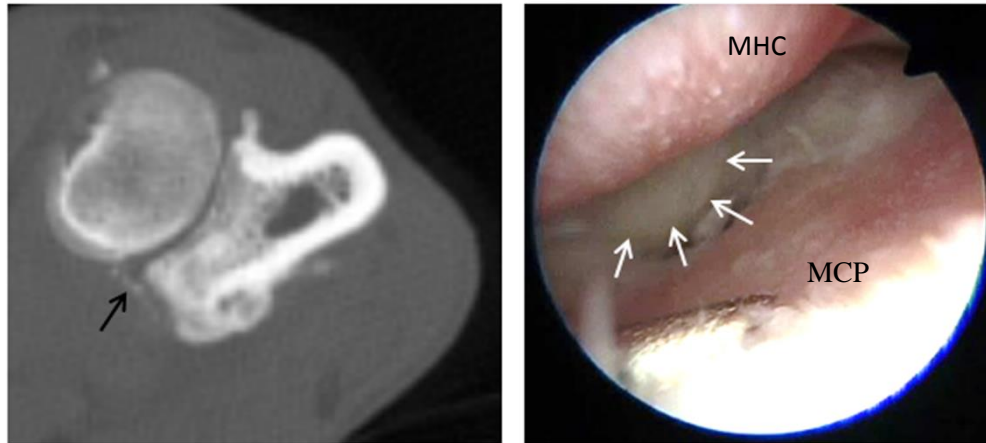
\*Lesions found during second-look arthroscopy of elbow joints that were already treated for medial coronoid disease.



**Figure 3:** Examples of dorsal and transverse plane computed tomographic images in a bone window (WL 500, WW 3000) of a lesion of the MHC (A, B, D, E) and the corresponding arthroscopic image (C, F). A: An indentation/lucent area in the MHC is visible (arrow). B: This image demonstrates a lucent area (arrow) on the MHC. C: The corresponding arthroscopic image of this elbow illustrates erosion of the medial elbow compartment with the presence of a subchondral bone defect (arrows) on the MHC. D, E: A lucent area (arrow) is visible on the MHC. F: The corresponding arthroscopic image of this elbow demonstrates medial compartment erosion with an even wear of the cartilage without a clear subchondral defect present.



**Figure 4:** Examples of transverse computed tomographic images in a bone window (WL 500, WW 3000) of a displaced fragment (arrow) of the MCP (A) and a calcified body at the level of the MCP (arrow) (B). The shape of the displaced fragment is compatible with the defect in the MCP. The calcified body demonstrates a more rounded appearance and the remaining part of the MCP has a blunt shape because of the previous arthroscopic treatment.



**Figure 5:** Transverse computed tomographic image in a bone window (WL 500, WW 3000) of an elbow joint that already has been treated arthroscopically for medial coronoid disease, illustrating multiple small fragments (arrow) at the level of the MCP. The corresponding second-look arthroscopic image demonstrates loose scar tissue (arrows). Most likely, these small fragments visible on computed tomography were embedded in the scar tissue, since they could not be identified during the arthroscopic joint inspection.



## **Discussion**

In this study, several CT signs were highly prevalent in the overall group of dogs with medial compartment erosion: periarticular osteophytosis, an abnormal shape of the MCP, a subchondral bone defect of the MHC, subchondral bone sclerosis of the MHC, ulnar trochlear notch and MCP, and flattening of the MHC. The prevalence of a subchondral bone defect of the MHC (96.4%) and lucency of the MCP (73.2%) on CT is higher in elbows with medial compartment erosion compared to the prevalence reported in elbows with medial coronoid disease (14, 27). The present study illustrates that the majority of the elbows with erosion of the medial joint compartment demonstrate a lucent area at the MHC on CT, indicative for a subchondral bone defect. Nonetheless, several of these joints showed an even loss of cartilage, without a clear subchondral bone defect, on arthroscopy. An explanation might be a gradual onset of cartilage loss before medial compartment erosion develops. Initial focal cartilage erosion, for example caused by impingement of a MCP fragment, can create a lucent zone in the subchondral bone of the MHC (14) before a more even cartilage erosion develops. Similarly, a high prevalence of lucent areas at the MCP is observed on CT in joints with medial compartment erosion. Possibly, this could also be explained by the gradual onset of cartilage loss. A similar heterogeneous aspect of the MCP with hypodense areas has also been described in elbow joints with lameness after the arthroscopic treatment of medial coronoid disease, diagnosed with loose scar tissue and/or erosion of the medial joint compartment during second-look arthroscopy (12).

Periarticular osteophytes were found in all joints with medial compartment erosion. A moderate correlation between CT osteophyte size and cartilage erosion of the medial elbow compartment has already been demonstrated (13). The diagnosis of erosion of the medial elbow compartment cannot be based on osteophyte size alone since some joints with medial compartment erosion have no or only small (< 2 mm) osteophytes (4, 9, 13). This was also the case in 8/56 joints in this study.

The prevalence of an abnormal shape of the MCP was high in this series. In the joints diagnosed with medial compartment erosion during a second-look arthroscopy the abnormal shape of the MCP on CT can be explained by the previous arthroscopic treatment. In the other joints it is unclear whether the abnormal shape of the MCP is a cause or a consequence of medial coronoid disease and/or medial compartment erosion (14, 27). In this study, the abnormal shape of the MCP often seemed to be associated with the presence of osteophytes.

The high prevalence of subchondral bone sclerosis of the ulnar trochlear notch (89.3%) might be caused by a chronic humeroulnar conflict, one of the proposed causes of medial coronoid disease and/or medial compartment erosion (28).

The relatively low percentage of fragmentation of the MCP on CT in this study (67.9%) emphasizes the fact that elbow pathology cannot be ruled out completely based on the absence of fissuring or fragmentation of the MCP on CT. The occurrence of medial compartment erosion without fissuring or fragmentation of the MCP or as a finding during second-look arthroscopy after treatment of medial coronoid disease has already been described (4, 9, 12).

In this CT study a different appearance was also observed between displaced fragments of the MCP and the more cranially situated calcified bodies, found in joints that were previously treated for medial coronoid disease. Those calcified bodies were considered to be calcifications of scar tissue or of the joint capsule, since no corresponding subchondral defect was recognized in these cases. Similar calcified bodies have already been described in a previous study concerning lameness after the arthroscopic treatment of medial coronoid disease, which also concluded that these calcifications were not genuine MCP fragments (12).

Fragments found via arthroscopy that were not observed on CT in 4 joints were very small (largest dimension < 2 mm). Possibly these fragments were partially cartilaginous and because of their small size overlooked on CT. On the other hand, CT demonstrated fragmentation of the MCP in 10 joints while no fragments were found during arthroscopy, of which 8 were second-look arthroscopies. Most likely, these fragments on CT represent small mineralized areas within the scar tissue or represent incompletely mineralized osteophytes in the MCP area (12, 13). In 2 joints, evaluation of CT images identified a calcified body in a very cranial position which could not be seen during arthroscopic joint inspection.

Radioulnar incongruity has been suggested as a causative factor for medial coronoid disease and medial compartment erosion (8, 29). Nevertheless, CT demonstrated a radioulnar step in only 35.7% of the joints with erosion of the medial joint compartment. However, the agreement between CT and arthroscopy for a radioulnar step was low. A similar finding has been reported earlier (14). Both CT and arthroscopy have been described to be appropriate techniques for the diagnosis of radioulnar incongruity (30-34). The value of CT for evaluating joint incongruity is limited to an evaluation of subchondral bone rather than alignment of joint surfaces (22, 33). The insertion of an arthroscope within the medial compartment of the elbow

can induce small changes in elbow incongruity (35). In addition, both CT and arthroscopy evaluate joint incongruity in a non-weightbearing position which can lead to misinterpretation.

CT is considered a sensitive technique for the diagnosis of flexor enthesopathy (25). An abnormal appearance of the medial humeral epicondyle was observed in 71.4% of the elbows with medial compartment erosion, indicative for the presence of concomitant flexor enthesopathy. Abnormalities at the enthesis of the flexor muscles are often found during arthroscopy in joints with (chronic) elbow dysplasia lesions or during second-look arthroscopy after earlier treatment of medial coronoid disease (12, 36). It has been suggested that chronic inflammation induced by the MCP lesion or trauma caused by the previous arthroscopic intervention could be a reason for the development of flexor enthesopathy (25). Further research should determine if the prevalence of concomitant flexor enthesopathy is higher in joints with chronic or more advanced elbow dysplasia lesions.

Despite the identification of 3 significant differences between the 3 groups of medial compartment erosion, distinguishing focal, diffuse and complete erosion on CT examination remains difficult. The presence of fragmentation of the MCP and widening of the humeroulnar joint space are non-specific signs, since they can also be present in joints with medial coronoid disease, without full-thickness cartilage loss (14, 24, 28). Some studies even indicate that humeroulnar incongruity may be a normal finding in canine elbows (28, 37, 38). Subchondral bone sclerosis of the radial head was only identified in joints with complete erosion. To the authors' knowledge this is the first CT study reporting changes in the lateral elbow compartment, as most studies are limited to changes in the medial elbow compartment. Further research is required to investigate the value of radial head subchondral bone sclerosis as a marker for complete erosion of the medial joint compartment.

In this study, the CT images were jointly evaluated by 2 observers. While consensus evaluation has been shown to be potentially more reproducible, it does not provide information on the intra- and interobserver agreement of diagnostic criteria (39). Ideally, diagnostic criteria have both a high intra- and interobserver agreement. Future studies should focus on investigating inter- and intraobserver agreement for the various criteria evaluated in this study. Another limitation is the limited number of joints included due to the retrospective nature of the study. Ideally, a larger group of joints was evaluated to increase statistical validity of the data.

Findings in this study contribute to the pre-surgical detection of medial compartment erosion via CT. Especially when no fragmentation of the MCP is observed on CT, attention should be paid to CT signs associated with medial compartment erosion before excluding elbow pathology. Although three variables were significantly different between the three groups of medial compartment erosion, arthroscopy is still indispensable to determine the extent of the cartilage erosion of the medial elbow joint compartment. The application of computed tomography arthrography might add to the pre-surgical diagnosis of erosion of the medial elbow compartment. However, the description of the use of computed tomography arthrography in canine elbows is limited to examination of normal cadaver elbows (40). It can be concluded that CT cannot replace arthroscopy for the diagnosis of medial compartment erosion and therefore both techniques should be considered complementary in the diagnosis of canine elbow disease.

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#### **Chapter 4**

**The effect of a bi-oblique dynamic proximal ulnar osteotomy as a single treatment in 8 skeletally immature dogs with an osteochondral fissure of the medial coronoid process: short- and long-term results.**



**The effect of a bi-oblique dynamic proximal ulnar osteotomy as a single treatment in 8 skeletally immature dogs with an osteochondral fissure of the medial coronoid process: short- and long-term results.**

*Adapted from: Coppieters E., Samoy Y., de Bakker E., Broeckx B., Verhoeven G., Gielen I., Van der Vekens E., Van Ryssen B. The effect of a bi-oblique dynamic proximal ulnar osteotomy as a single treatment in 8 skeletally immature dogs with an osteochondral fissure of the medial coronoid process: short- and long-term results. Veterinary Comparative Orthopaedics and Traumatology 2016, in revision.*



## **Summary**

Treatment of medial compartment erosion is challenging because of the limited regeneration capacity of cartilage. Therefore research into preventive measures is warranted.

The aim of this study was to report our clinical experience with the treatment of an osteochondral fissure of the medial coronoid process (MCP) by a bi-oblique dynamic proximal ulnar osteotomy (BODPUO) in skeletally immature dogs (< 10 months). BODPUO as a single treatment leaves the joint surface intact while the intra-articular forces are altered.

Eight dogs (8 joints) diagnosed with an osteochondral fissure of the MCP based on elbow radiography, computed tomography and arthroscopy were treated with BODPUO. Preoperative clinical and radiographic findings were compared to the findings in the long-term ( $\geq 1$  year postoperatively). Short-term follow-up demonstrated that lameness completely resolved after treatment with BODPUO in 4 dogs (50%). Lameness persisted or recurred in the other 4 dogs (50%). After arthroscopic removal of the fissured part of the MCP lameness improved in these 4 dogs as well. Long-term follow-up revealed an “excellent” or “good” outcome in all but one dog, based on owner assessment. However, an increase in periarticular osteophytosis was found in 7 joints (87.5%).

In conclusion, treatment of an osteochondral fissure of the MCP with BODPUO without concurrent arthroscopic treatment has the ability to resolve lameness associated with the osteochondral fissure of the MCP in skeletally immature dogs. However, half of the cases in this study underwent additional arthroscopic procedures at follow-up to improve outcome.

### **Introduction:**

Elbow dysplasia is a frequent cause of lameness in young large breed dogs (1-3). Fissuring or fragmentation of the medial coronoid process (MCP) is the most common pathology of the elbow dysplasia complex (1, 3). The exact etiopathogenesis of disease of the MCP has not yet been elucidated. Besides a radioulnar step and mismatch between the humerus and the ulnar notch (4, 5), radioulnar incongruity in a transverse plane may also be involved in the pathogenesis of medial coronoid disease (6). Incongruity between the radial head and the radial incisure of the ulna, together with abnormal dynamic muscular forces (e.g. biceps brachialis complex) may contribute to the development of MCP disease (7-9). Histological studies confirmed that subchondral fatigue microdamage, possibly caused by repetitive excessive loading of the MCP, could be associated with MCP fragmentation (10, 11). Nevertheless, also a disturbance of endochondral ossification has been found to be involved in the development of MCP disease (12).

Conventional treatment of a fissured/fragmented MCP consists of the removal of the fissured/fragmented part of the coronoid by arthrotomy or arthroscopy (3, 13). Surgical removal of the pathologic tissue generally relieves pain, but cannot prevent progression of osteoarthritis in the long term (14-16). To address radioulnar incongruity, a proximal ulnar osteotomy has been described as an additional treatment option (17, 18). Movement of the proximal segment of the ulna might permit dynamic unloading or redistribution of forces along the contact areas of the MCP (19). An ulnar osteotomy in the proximal third of the ulna permits an increased movement of the proximal segment, compared to a more distal osteotomy (19, 20). Movement of the proximal ulnar segment has been described in several planes. A caudal displacement of the proximal ulnar segment, combined with a proximal translation is likely due to the traction of the triceps muscles (20). A proximal ulnar osteotomy improves radioulnar and humeroulnar congruence because of a complex three-dimensional rotation of the proximal ulnar segment rotating the MCP distally in relation to the radial head (21). In addition, a bi-oblique dynamic proximal ulnar osteotomy (BODPUO) generates an increase in radioulnar joint space and a cranially directed rotation of the MCP (6). This disassociation between the ulnar incisure and the radial head could potentially reduce torsional conflict between the radius and the ulna (6).

The purpose of this pilot study was to report our clinical experience, including short- and long-term follow-up, of treatment of an osteochondral fissure of the MCP with a BODPUO,

without concurrent arthroscopic treatment, in skeletally immature dogs (< 10 months). We assumed that a BODPUO as a single treatment, without removal of the fissured part of the MCP, would redistribute forces along the MCP and reduce impingement between the MCP and the radius, thereby eliminating pain and leading to resolution of lameness.

### **Material and methods:**

This prospective study was performed according to the guidelines of the Animal Care Committee of the University of Ghent.

#### ***Dogs***

All dogs included in this study were skeletally immature dogs (< 10 months) presented between March 2011 and September 2013 and diagnosed with a unilateral osteochondral fissure of the MCP using computed tomography (CT) and arthroscopic inspection of the elbow joint.

#### ***Diagnosis and treatment***

Each dog demonstrated clinical signs of elbow disease. Radiographic examination was performed to confirm the presence of elbow pathology and to determine the initial amount of osteoarthritis. Radiographic examination included a mediolateral extended and flexed view and a craniocaudal (15°-pronation) view of the affected elbow. The radiographic amount of periarticular osteophytosis was scored, according to the IEWG-guidelines (International Elbow Working Group), as: 0 = no osteophytes; 1 = osteophytes  $\leq$  2 mm; 2 = osteophytes > 2-5mm, 3 = osteophytes > 5 mm (22). The radiographic amount of subchondral bone sclerosis of the ulnar trochlear notch was subjectively assessed pre- and postoperatively. CT examination was performed with the dog under general anesthesia, using a 4-slice helical CT device (CT-scanner, LightSpeed, GE Medical Systems, Milwaukee, WI). Dogs were positioned in left lateral recumbence with the front legs parallel and extended cranially. The head of the dogs was pulled back with right lateroflexion of the cervical spine to remove the head from interfering with the scan (23). Both elbows were scanned at the same time (23). On CT a fissure was diagnosed when a lucent line was observed, dividing the MCP. Since CT is not able to make the differentiation between a non-displaced fragment and a fissure of the MCP, the diagnosis of an osteochondral fissure of the MCP needed to be confirmed arthroscopically by direct inspection and probing of the lesion. (24),

Arthroscopic inspection was performed consecutively and conducted with a 2.4 or 1.9 mm arthroscope (Richard Wolf, Knittlingen, Germany) using a standard medial approach (25). An osteochondral fissure of the MCP was confirmed when a discrete cartilage fracture line was seen and no mobility was noticed during pronation and supination of the leg or when probed (24). Only joints with a normal cartilage surface, except for the osteochondral fissure of the



MCP, were included. Dogs with arthroscopic evidence of concurrent elbow pathology were excluded. Initially, no arthroscopic treatment was performed, leaving the fissured part of the MCP in place. In case of an unsatisfying result after the initial treatment with a BODPUO, a second arthroscopy was performed to remove the fissured part of the MCP with debridement of the remaining part of the MCP (13, 26).

Joint incongruence was determined based on CT and arthroscopic findings. Radioulnar incongruence was classified as absent (no step), mild (step 0 - 2 mm) or obvious (step  $\geq$  2 mm) (27).

After arthroscopic confirmation of the diagnosis of an osteochondral fissure of the MCP a BODPUO was performed. The osteotomy was performed via a caudolateral approach, at the level of the junction of the proximal and the mid-third of the ulna, proximal to the interosseous ligament (20). The osteotomy was directed from distomedial to proximolateral and craniodistal to caudoproximal in an angle of approximately 40° (20, 21, 28, 29).

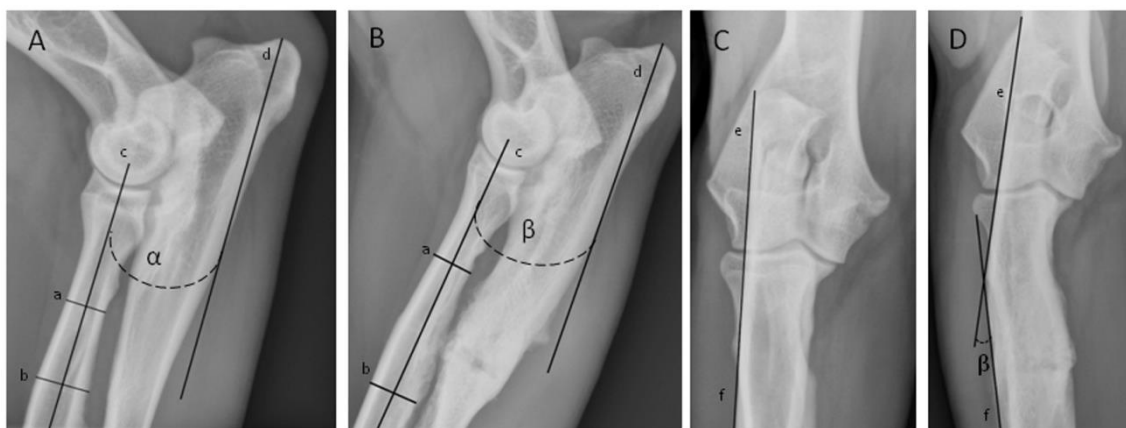
### ***Postoperative management***

A non-steroidal anti-inflammatory drug (carprofen, 4 mg/kg IV) and an antibiotic (amoxicillin/clavulanic acid, 8.75 mg/kg SC) were given at the beginning of the surgical procedure, and administered orally for 3 weeks (carprofen, daily 1 week 4 mg/kg and daily 2 weeks 2 mg/kg) and 5 days (amoxicillin/clavulanic acid, 12.5 mg/kg twice daily) postoperatively, respectively. In addition, methadone (0.2-0.3 mg/kg IV every 4 hours) was administered for the first 24 hours postoperatively. A soft-padded bandage was applied for the first 24-48 hours postoperatively. Dogs were restricted to leash walking for the following 12 weeks, allowing a slow increase of activity over time.

### ***Follow-up***

All dogs returned for short-term follow-up examination 4 weeks and 12 weeks postoperatively. In addition, owners were invited to return for a long-term follow-up examination 1 year and 2 years postoperatively (30). Follow-up visits comprised a lameness evaluation (including video recordings), a physical examination and radiographic examination (mediolateral and craniocaudal radiographs) of the operated elbow. During physical examination ipsilateral thoracic limb muscle atrophy, joint effusion, range-of-motion and elbow pain were subjectively evaluated by the first author. These findings were compared with the preoperative physical examination findings. Short-term radiographic examination at

4 and 12 weeks postoperative was used to assess healing of the osteotomy. Healing was considered ‘complete’ when mineralized bridging of the osteotomy was observed between three cortices on orthogonal radiographs. In case of persistent lameness at the 12-week follow-up visit, further short-term follow-up was conducted on an individual basis. Long-term follow-up radiographs were used to assess progression of osteoarthritis. In addition, the displacement of the proximal ulnar segment in the caudal and lateral direction was measured on the mediolateral and craniocaudal radiographs respectively (Figure 1). During long-term follow-up visits owner assessment was conducted by completing a modified force plate validated questionnaire (table 1) (31, 32). Questions were answered on a scale from 0 to 5, added up to a total outcome score. A score of 0 - 3 was considered an “excellent” outcome, a score of 4 - 8 a “good” outcome, a score of 9 - 15 an “acceptable” outcome and a score of > 15 an “unsatisfactory” outcome. Dogs were videotaped walking and trotting away and towards the video camera and laterally while turning. Video sequences (30-75 seconds) were made at every visit and showed independently to the observers in a random order. Three independent observers (EC, BVR and GV) scored lameness (preoperatively and postoperatively) on a modified numeric rating scale from 0 to 10 (0= no lameness and 10= non-weight bearing) based on the video sequences (33). All observers were highly experienced in lameness evaluation. This 11-point numeric rating scale has been developed for grading lameness in horse (34), but has been used in dogs as well (33).



**Figure 1: Measurement of the displacement of the proximal ulnar segment in caudal and lateral direction after performing a bi-oblique dynamic proximal ulnotomy. On the mediolateral radiographic views (A, B) the angle was measured between the functional axis of the proximal radius (c) and a tangent of the proximal segment of the ulna, starting from the most proximal point of the olecranon (d). To retrieve the functional axis a line was drawn through the middle of line a and b. On the craniocaudal radiographic views (C, D) the angle was measured between a tangent of the proximal segment of the ulna (e) and a tangent of the distal part of the ulna (f). Comparing the angle preoperative ( $\alpha$ ) to the angle after complete healing of the osteotomy site ( $\beta$ ) results in an angle of displacement in the caudal direction and in the lateral direction.**

**Table 1: Owner questionnaire for long-term follow-up. A total outcome score of 0 – 3 was considered an “excellent” outcome, a score of 4 - 8 a “good” outcome, 9 – 15 an “acceptable” outcome and > 15 an “unsatisfactory” outcome.**

Question	Owner assessment
1. Indication of lameness when walking on surgery limb?	<p>0 1 2 3 4 5</p> <p>No lameness at any time Holds leg up most of the time</p>
2. How is the activity during the day?	<p>0 1 2 3 4 5</p> <p>Very active (runs and jumps a lot) Not active (Lies around most of the time)</p>
3. How often does the dog gets exercise?	<p>0 1 2 3 4 5</p> <p>A lot (several walks a day) No exercise</p>
4. What is the willingness to play voluntarily?	<p>0 1 2 3 4 5</p> <p>All day spontaneously Moves hardly</p>
5. Stiffness when arising for the day??	<p>0 1 2 3 4 5</p> <p>Never Always</p>
6. Stiffness at the end of the day (after activities)?	<p>0 1 2 3 4 5</p> <p>Never Always</p>

## Results

### *Study population and initial clinical findings*

Table 2 demonstrates the breed, gender, weight and age of the eight dogs included in this study. Abnormal findings on orthopedic examination were discomfort or pain at flexion and/or extension of the elbow (n= 7), effusion of the elbow joint (n = 6), reduction of elbow range-of-motion (n = 1) and ipsilateral thoracic limb muscle atrophy (n = 6). The median preoperative degree of lameness of each dog is illustrated in table 3. Table 4 shows the preoperative degree of periarticular osteophytosis. Subchondral bone sclerosis of the ulnar trochlear notch was present in all elbows. Based on CT-examination and arthroscopic joint inspection, all joints were considered mildly incongruent (radioulnar step 0 - 2 mm). The most caudo-proximal point of the osteotomy was located at on average 36% (range 28 - 46%) of the total ulnar length from the olecranon process (table 2).

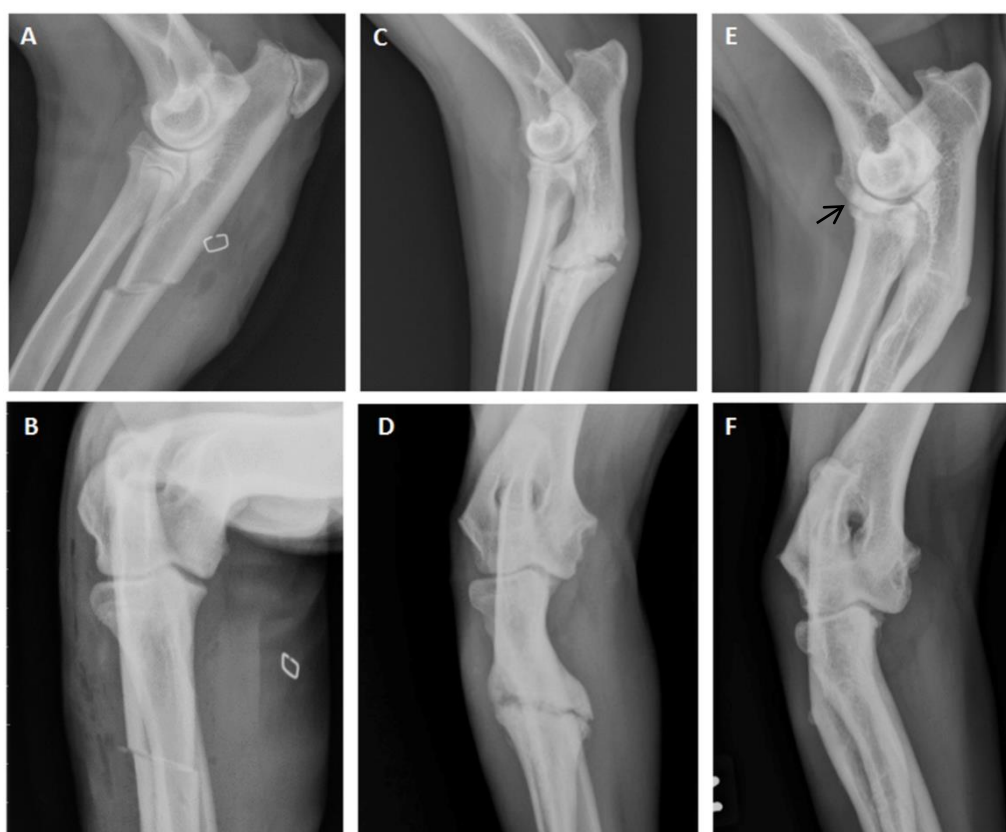
**Table 2: Information on the breed, gender, weight and age distribution as well as the elbow affected by an osteochondral fissure of the medial coronoid process and the position of the osteotomy, compared to the full ulnar length (29), of the eight dogs included in this report.**

		Breed	Gender	Age at diagnosis	Weight	Elbow	Osteotomy position
<b>G R O U P 1</b>	<b>Dog 1</b>	Crossbreed-Border collie	Male neutered	9.5 months	24 kg	Right	42%
	<b>Dog 2</b>	Labrador Retriever	Male	8.5 months	28 kg	Left	36%
	<b>Dog 3</b>	Border Collie	Female	9.0 months	14.5 kg	Left	28%
	<b>Dog 4</b>	Bordeaux Dog	Female	8.5 months	47 kg	Left	41%
<b>G R O U P 2</b>	<b>Dog 5</b>	Crossbreed – Bull Mastiff	Male	8.0 months	53.5 kg	Right	29%
	<b>Dog 6</b>	Rottweiler	Female	8.0 months	34.5 kg	Right	34%
	<b>Dog 7</b>	Labrador Retriever	Male	7.5 months	33.5 kg	Left	46%
	<b>Dog 8</b>	Majorca Shepherd Dog	Male	7.0 months	31 kg	Left	35%

### *Short-term follow-up*

At the first follow-up visit, 4 weeks postoperatively, a clear caudal displacement of the distal part of the proximal ulnar segment was noticed in all joints. An onset of bony callus formation was visible in 7 dogs. In dog 3 the edges of the ulnar segments seemed rounded and no bony callus formation was visible. Obvious lameness, associated with the ulnar osteotomy, was present in all dogs.

At the second follow-up visit, 3 months postoperatively, none of the dogs showed complete healing of the ulnar osteotomy; five dogs showed a good progression of healing of the osteotomy (Figure 2). In dogs 1 and 4 a slow increase in mineralized callus formation was noticed but a large radiolucent gap was still present between the ulnar segments. In dog 3 the edges of the ulnar segments remained rounded. This complication of slow bone healing was treated with ultrasound treatment (Sonopuls 190, Enraf-Nonius, The Netherlands) during two weeks (8 sessions, 9 to 11 weeks postoperatively) to increase vascularization and thus stimulate bone healing (Figure 3). An additional finding on radiographic examination was the presence of a periosteal reaction on the caudal cortex of the radius at the level of the ulnar osteotomy in 4 dogs (dogs 1, 2, 3 and 4). The degree of lameness varied from practically resolved (1/10) to obvious lameness (7/10) (table 3). Despite dog 3 being diagnosed with a non-union of the BODPUO-site at long-term evaluation, lameness was minimal at the 3 month postoperative evaluation.



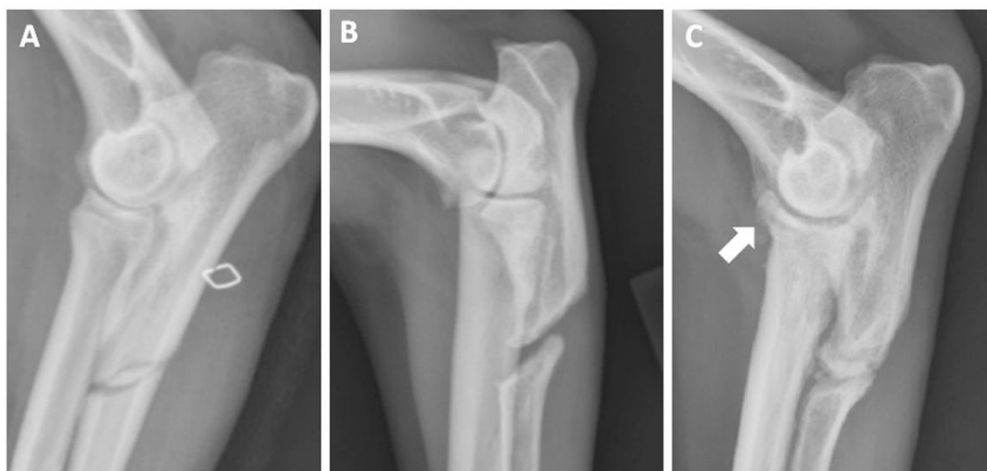
**Figure 2: Mediolateral and craniocaudal radiographic views of the elbow of dog 6: Immediately postoperatively (A, B), 3 months (C, D) and 2 years (E, F) after bi-oblique dynamic proximal ulnar osteotomy. Three months postoperatively a clear displacement of the proximal ulnar segment is visible and a good progression of bone healing is present at the level of the ulnar osteotomy (C, D). Two years postoperatively a progression in the degree of elbow osteoarthritis is visible with especially a large osteophyte on the radial head (arrow) (E, F).**

**Table 3: Median lameness scores, based on the scores of 3 independent observers, in 8 dogs with an osteochondral fissure of the medial coronoid process managed with a bi-oblique dynamic proximal ulnar osteotomy (BODPUO): short- and long-term follow-up. Dogs 1 to 4 (= Group 1) were treated by a bi-oblique dynamic ulnar osteotomy only. Dogs 5 to 8 (= Group 2) underwent additional arthroscopic treatment 4.5 to 8 months after the ulnar osteotomy. An 11-point numeric rating scale was used to grade lameness (0 = no lameness, 10 = non-weight bearing) (33, 34). (po: postoperatively, NA: not available, \* not yet available)**

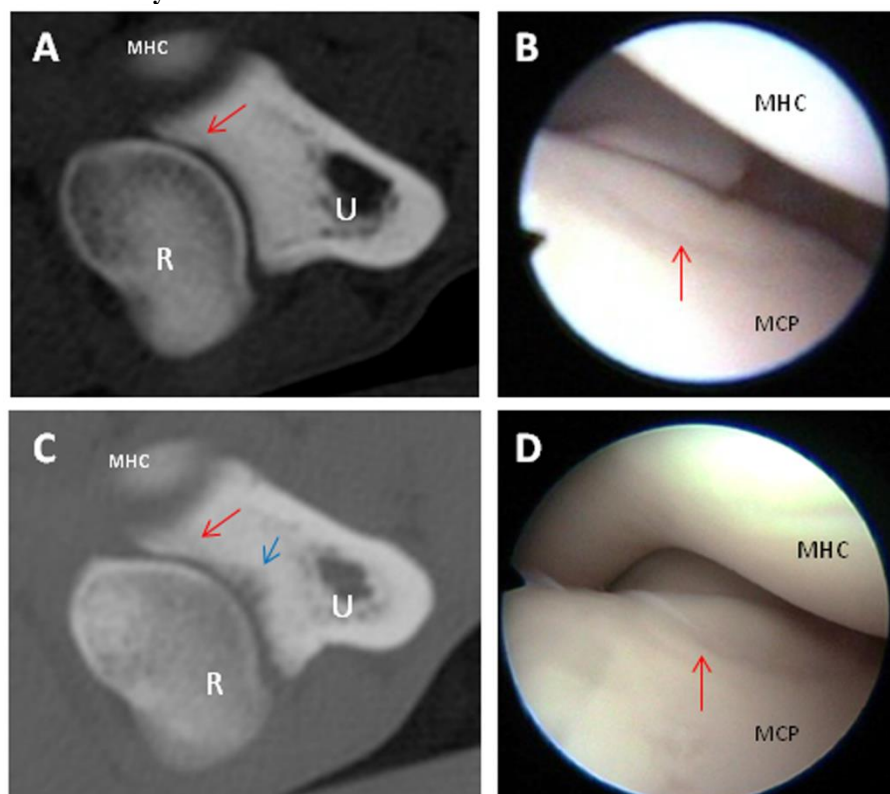
		Median lameness score				
		Preoperative	3 months po	1 year po	2 years po	4 years po
<b>G R O U P  1</b>	<b>Dog 1</b>	1	1	NA	NA	0
	<b>Dog 2</b>	6	5	0	0	NA
	<b>Dog 3</b>	6	1	2	2	2
	<b>Dog 4</b>	7	5	0	1	*
<b>G R O U P  2</b>	<b>Dog 5</b>	6	7	0	2	NA
	<b>Dog 6</b>	8	6	NA	4	*
	<b>Dog 7</b>	4	2	0	0	*
	<b>Dog 8</b>	4	3	NA	0	*

Additional short-term follow-up visits were performed in 6 dogs (dogs 1, 4, 5, 6, 7, 8) because of an unacceptable degree of postoperative lameness and/or problems with healing of the osteotomy. In dogs 1 and 4 complete radiographic healing of the osteotomy site was documented 4.5 and 6 months postoperatively, respectively and lameness had completely resolved in both dogs. In dog 7 lameness resolved 4 months postoperatively but recurred 6 months postoperatively. Lameness did not resolve in another three dogs (dogs 5, 6, 8). Since additional treatment with NSAIDs did not lead to improvement in dogs 5, 6, 7 and 8 arthroscopic surgery was advised to remove the fissured part of the MCP anyway. Surgery was only performed after complete radiographic healing of the ulnar osteotomy was documented and all other possible causes of lameness were excluded. The second arthroscopic surgery was performed at 5.5 months, 4.5 months, 7 months and 8 months after the BODPUO, in dogs 5, 6, 7 and 8 respectively. Arthroscopy confirmed that the osteochondral fissure of the MCP had remained unchanged in all 4 joints and that also the cartilage surface had remained intact (figure 4), except for one joint (dog 5) that developed a modified Outerbridge grade 1 cartilage pathology of the MCP. Prior to the second surgery CT-examination was repeated in 2 dogs (dog 7 and 8), demonstrating an unchanged

appearance of the lesion of the MCP and a mild increase of osteoarthritis compared to the first CT-examination (figure 4). Obvious improvement of lameness was noticed by the owners 6 weeks, 3 months, 1 week and 6 weeks after removal of the fissured MCP, respectively.



**Figure 3: Radiographic views of the elbow of dog 3 following bi-oblique dynamic proximal ulnar osteotomy: Immediately postoperatively (A), 3 months postoperatively (B) and 2 years postoperatively (C). A: A bi-oblique osteotomy at the level of the junction of the proximal and mid-third of the ulna was performed. B: A radiographic delayed union of the ulnar osteotomy is visible. C: A radiographic non-union of the ulnar osteotomy is present. An increase in elbow osteoarthritis is visible with especially a large osteophyte on the radial head (arrow). A periosteal reaction on the caudal cortex of the radius at the level of the ulnar osteotomy is visible.**



**Figure 4: Transverse computed tomographic (CT) images of dog 7 and corresponding arthroscopic images at the time the BODPUO was performed (A and B) and at the second arthroscopic surgery 7 months later (C and D). A and B: An osteochondral fissure of the medial coronoid process is visible (red arrow). C and D: The osteochondral fissure of the medial coronoid process remained unchanged (red arrow). Some radiolucencies at the radial incisure of the ulna are visible on the CT image (blue arrow). (R: radius, U: ulna, MCP: medial coronoid process, MHC: medial part of the humeral condyle).**

**Long-term follow-up**

All dogs returned for at least one long-term follow-up visit (> 1 year postoperatively) (table 3 and 4).

**Table 4: Progression of radiographic degree of periarticular osteophytosis in 8 dogs with an osteochondral fissure of the medial coronoid process, managed with a bi-oblique dynamic proximal ulnar osteotomy (degree 0 = no osteophytes, degree 1 = osteophytes  $\leq$  2mm, degree 2 = osteophytes > 2-5 mm, degree 3 = osteophytes > 5 mm) (22). (po: postoperatively, NA: not available, \* not yet available)**

		Radiographic degree of periarticular osteophytosis			
		Preoperative	1 year po	2 years po	4 years po
G R O U P  1	Dog 1	0	NA	NA	0
	Dog 2	0	2	2	NA
	Dog 3	0	2	2	2
	Dog 4	0	1	1	*
G R O U P  2	Dog 5	0	3	3	NA
	Dog 6	1	NA	2	*
	Dog 7	0	2	2	*
	Dog 8	0	NA	1	*

In dogs 1 to 4 (= Group 1) a BODPUO resolved lameness in the short-term; long-term lameness evaluation revealed that three of these dogs were not lame. One dog, Dog 3, showed a mild lameness (median lameness score 2/10) and was diagnosed as having developed a radiographic non-union of the BODPUO (table 3). Long-term clinical examination (1 or 2 years postoperatively) demonstrated that the range of motion of the elbow joint remained unchanged in 3 dogs of Group 1, and decreased in 1 dog compared to preoperatively. An improvement in pain reaction and muscle mass was also noticed in 3 of those dogs. Elbow joint effusion remained unchanged in 2 dogs, and increased in 2 dogs. All elbow joints in Group 1 demonstrated an increase in the radiographic degree of periarticular osteophytosis, except dog 1 which remained free from osteophytes 4 years postoperatively (table 4). In the two dogs that returned for a second long-term follow-up visit, the degree of osteoarthritis and the clinical findings remained unchanged compared to the previous follow-up visit. In dog 3 a mild decrease in range of motion was observed at the third follow-up visit 4 years postoperatively. Owners of all 4 dogs of Group 1 rated the outcome after surgery as “excellent”. The dogs were able to walk more than 1 hour a day and to run and jump unrestrained. None of the dogs in Group 1 were receiving any medication.

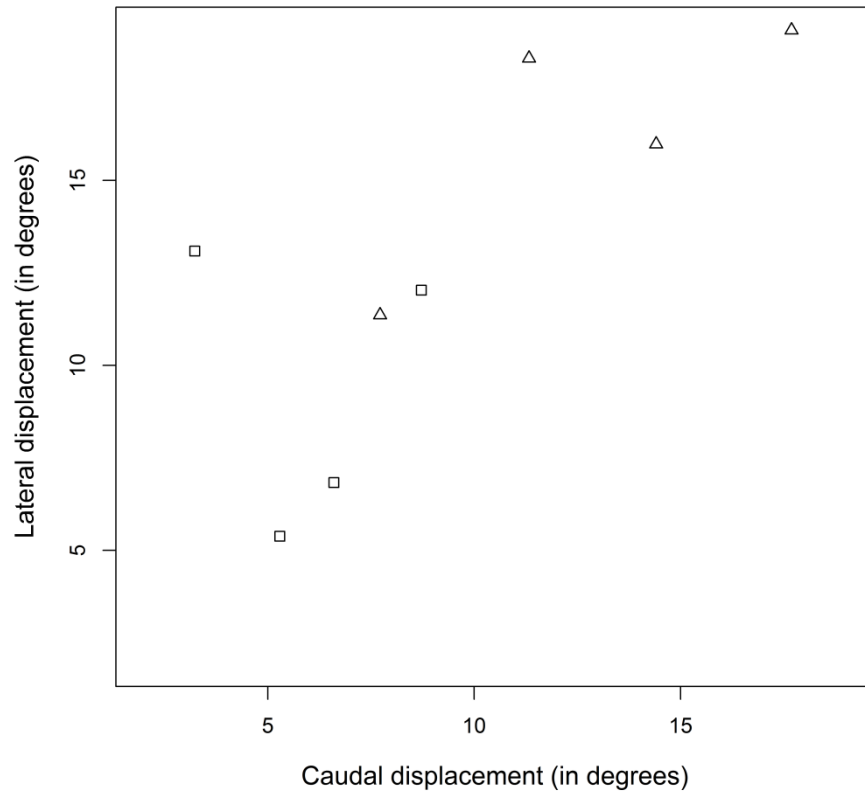


In dogs 5 to 8 (= Group 2) lameness recurred or persisted after BODPUO and a second arthroscopic procedure was performed. Long-term lameness evaluation indicated that 3 dogs (dog 5, 7 and 8) in Group 2 were sound. However, in dog 5 a mild degree of lameness redeveloped. According to the owner, this lameness was only intermittent and the dog had sound periods. In dog 6 a moderate degree of lameness persisted (table 3). An improvement in pain reaction was observed in all dogs in Group 2 compared to preoperatively. An improvement in thoracic limb muscle mass was noticed in 3 dogs. The range of motion of the elbow joint remained unchanged in 2 dogs but decreased in dog 6 and 8 compared to preoperatively. Joint effusion remained unchanged in dog 6 and 8, decreased in dog 7 and increased in dog 5. All elbow joints of Group 2 demonstrated an increase in the radiographic degree of periarticular osteophytosis (table 4). In dogs 5 and 7, which returned for a second long-term follow-up visit, the degree of periarticular osteophytosis and the clinical findings remained unchanged compared to the previous visit. According to the owners of the dogs in Group 2, the outcome after treatment was considered “excellent” in 2 dogs (dogs 7 and 8), “good” in dog 5 and “acceptable” in dog 6. Dogs 5, 7 and 8 were able to walk more than 1 hour a day and to run and jump unrestrained. In dog 6 lameness increased after unrestrained playing. Dogs 7 and 8 received nutraceuticals containing glucosamines daily, and dog 5 received a non-steroidal anti-inflammatory drug when lameness was noticed by the owner. Dog 6 never received any medication.

During the evaluation of the radiographic osteophyte size, it was noticed that the largest osteophyte was always present on the radial head (figure 3). No remarkable increase or decrease in subchondral bone sclerosis of the ulnar trochlear was noticed in all 8 elbow joints. In addition, the periosteal reaction on the caudal radial cortex at the level of the BODPUO noticed at the 3 month postoperative evaluation in dogs 1 - 4 remained present at all long-term evaluations.

### ***Displacement of the proximal ulnar segment***

On radiographic examination, the position of the proximal ulnar segment preoperatively was compared with the position after complete healing of the osteotomy site (Figure 1). In general, a more excessive displacement in both caudal and lateral direction occurred in Group 2 compared to Group 1 (Figure 5).



**Figure 5: Illustration of the amount of displacement of the proximal ulnar segment in caudal and lateral direction after a bi-oblique proximal ulnar osteotomy (BODPUO) in 8 dogs with an osteochondral fissure of the medial coronoid process. In dogs 1 – 4 (Group 1 = □) lameness was managed with a BODPUO as single treatment method. In dogs 5 – 8 (Group 2 = Δ) an additional arthroscopic debridement of the fissured medial coronoid process was required to improve lameness.**

## **Discussion**

This clinical report describes a novel treatment approach for an osteochondral fissure of the MCP in skeletally immature dogs in an attempt to find an alternative to arthroscopic treatment that can limit progression of osteoarthritis and thereby enhance long-term outcome.

Only skeletally immature dogs were included to ensure the presence of minimal degenerative changes in the joint at the time of treatment. In addition, good healing of the osteotomy site was expected because of the young age.

Performing BODPUO was able to completely resolve lameness in 4 out of 8 dogs in this study. Additionally, the elbow of dog 1 remained free from osteophytes 4 years postoperatively. This illustrates that BODPUO may resolve lameness along with a limited progression of osteoarthritis in the long-term. However, clinical outcome after BODPUO was unsatisfactory in 4 dogs (Group 2), requiring additional arthroscopic surgery to remove the fissured part of the MCP. This success rate of only 50% is quite low compared to the good outcome reported after arthroscopic treatment in about 90% of the cases and after medical treatment in 56 - 77 % of the cases (16, 36). The relatively low success rate in our study is also in contrast with findings in another study reporting a significant decrease in lameness score after BODPUO as a single treatment method for developmental elbow diseases, including medial coronoid lesions (29). Nevertheless, the postponed second arthroscopy did not negatively influence joint pathology in the long-term in our study. Probably additional (unknown) parameters should be taken into account when patients are selected for a treatment with BODPUO.

Overall, an increase of the radiographic degree of osteoarthritis was observed in all but one dog. Although the radiographic degree of osteoarthritis is associated with the amount of cartilage damage (24, 37), a second-look arthroscopy would be necessary to definitively evaluate progression of cartilage damage in the long-term. Short-term second-look arthroscopy in 4 dogs in this study demonstrated nearly no arthroscopically visible progression of cartilage damage. This second-look arthroscopy and additional treatment performed in joints in Group 2 might have influenced progression of osteoarthritis as well. A remarkable finding was that the largest osteophyte developed on the cranial aspect of the radial head, while other osteophytes were often less prominent. This osteophyte can explain the decrease in range-of-motion observed at long-term follow-up in half of the dogs. In addition, the prominent radial osteophyte generates a remarkable increase in degree of

osteoarthritis. However, if the radial osteophyte is omitted as a degenerative finding, only one joint still showed grade 2 osteoarthritis (dog 6), and all other joints only demonstrated degree 0 or 1 at the long-term follow-up radiographs (22).

In this study, a non-union (Dog 3) and a delayed union (Dog 4) of the ulnar osteotomy occurred. This complication with bone healing was an unexpected finding since one of the reasons the osteotomy is performed in a bi-oblique manner is to avoid extreme tilting of the proximal segment and thus reduce problems with bone healing. Also because of the young age of the dog at the time of treatment, this non-union was unexpected. In another study reporting 2 cases of a delayed union after performing BODPUO as well, the osteotomy angle or height was not significantly different for complicated and uncomplicated elbows (29). Despite this complication, the two dogs in our study had an “excellent” outcome.

In this study, a periosteal reaction on the caudal radial cortex at the level of the ulnar osteotomy was noticed in 4 dogs but a synostosis never occurred. This periosteal reaction was found in the elbows with the least displacement of the proximal ulnar segment that demonstrated an “excellent” outcome after treatment with a BODPUO. Possibly the periosteum of the caudal cortex of the radius was disturbed during surgery resulting in a periosteal reaction, or the large callus formed after the ulnar osteotomy caused irritation at the caudal aspect of the radius. In the authors’ experience, in rare cases this kind of periosteal reaction can evolve into a synostosis between radius and ulna.

Measurements of the displacement of the proximal ulnar segment in caudal and lateral direction showed a more excessive displacement in both caudal and lateral direction in Group 2. Abnormal migration of the proximal ulnar segment has been reported as a possible complication after BODPUO (18, 29). Therefore, the ulnar osteotomy is performed in a bi-oblique manner to prevent extreme tilting. Nonetheless, the ideal angulation of a BODPUO is still undetermined since no significant difference in the angle of the osteotomy has been found between complicated and uncomplicated elbows (29). Also no exact data are available on which amount of migration is considered abnormal or excessive. Nevertheless, measurements in this study confirm that a higher degree of displacement of the proximal ulnar segment might be associated with a less favorable outcome.

We were not able to determine why a BODPUO as a single treatment was successful to resolve lameness in only 4 of 8 dogs. Possibly other factors, such as the shape of the ulnar incisure or musculature influence the movement of the proximal ulnar segment and thereby

have an effect on the result after BODPUO. Further research is required to determine influencing factors and their effect on clinical outcome. Therefore, it is currently not possible to predict which joints would benefit from a BODPUO and which would not.

The major limitation of this pilot study is the small amount of dogs included, making it difficult to draw conclusions about the success rate of a BODPUO as a single treatment or factors influencing a successful outcome. A second limitation is the subjective evaluation of lameness and clinical outcome. We tried to limit the subjectivity of this evaluation by using three independent observers randomly evaluating the video sequences. However, the authors recognize these limitations and a repeated study with an improved design and a larger treatment group combined with a control group would be indicated. A third limitation concerns the measurement of the displacement of the proximal ulnar segment. To the authors' knowledge there is no validated method described to measure the displacement of the proximal ulnar segment after BODPUO. Although it is described that the proximal ulnar segment makes a 3D-movement after BODPUO (21) we were only able to measure 2D-displacement based on the radiographs. Nevertheless, these 2D measurements included the caudal tipping, the assumed main movement of the proximal ulnar segment (21).

This pilot study showed that a BODPUO can be applied as a single treatment method in skeletally immature dogs diagnosed with an osteochondral fissure of the MCP with no concurrent arthroscopic procedures performed. With this novel approach, lameness resolved in only half of the dogs (4/8). However, of the four dogs in which lameness did not resolve or recurred, the fissured MCP was arthroscopically debrided after which lameness resolved in three dogs. Overall, long-term outcome was classified by the owners as “excellent” in six dogs, “good” in one dog and “acceptable” in one dog. This promising outcome warrants further investigation of this novel treatment option for management of an osteochondral fissure of the MCP in skeletally immature dogs and thereby identify specific patient selection criteria to improve success rates.

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#### **SECTION IV**

### **GENERAL DISCUSSION**



## **GENERAL DISCUSSION**

Elbow dysplasia is a frequent cause of front limb lameness in young medium and large breed dogs (1-4). Several environmental factors and a complex genetic heritability contribute to predisposing dogs to develop elbow dysplasia (2). Medial *coronoid* disease, encompassing all types of lesions of the medial coronoid process, is the most common manifestation of elbow dysplasia (1-3). Arthroscopic joint inspection is the gold standard for the evaluation of articular joint cartilage and allows subsequent treatment (5-8). A good outcome in up to 90% of the dogs is reported after arthroscopic treatment (9). Nevertheless, a radiographic progression of degenerative changes is commonly recognized (9-11).

Erosion of the medial compartment, previously also called medial compartment disease, is considered to be an advanced stage of medial *coronoid* disease (8, 12). Direct visualization of articular cartilage damage of the canine elbow via standard medical imaging techniques such as radiography and computed tomography is impossible and requires arthroscopic joint inspection (5, 8, 13). Due to the more routine use of arthroscopy, diagnosis of cartilage damage in the medial elbow compartment increased over the last decade (8). Since the regenerative capacity of cartilage is limited, the presence of these full-thickness cartilage erosions significantly influences prognosis after treatment (8, 14). Difficulties in the diagnosis and treatment of these cartilage erosions encouraged further research into this condition.

A difficulty we encountered was the confounding terminology used to address full-thickness cartilage erosion of the medial elbow compartment in dogs. Therefore, we introduced the more descriptive term ‘medial compartment erosion’ since ‘medial *compartment* disease’ and ‘medial *coronoid* disease’ were often used interchangeably, creating confusion. Although the prevalence, diagnosis and treatment of fissuring and fragmentation of the medial coronoid process, attributed to physiologic overload (14-16), have been extensively studied, specific information on erosion of the medial compartment was limited. In the existing literature erosion of the medial compartment is most commonly described concomitant to fissuring/fragmentation of the medial coronoid process in advanced cases of medial *coronoid* disease (3, 17, 18). In these cases the cartilage damage is often attributed to the presence of the fissured/fragmented part of the medial coronoid process and/or humeroulnar conflict (19, 20). However, in some studies medial compartment erosion has been diagnosed as a primary condition, without concomitant lesions of the medial coronoid process (17, 21). Additionally, the development of severe cartilage damage in the medial elbow compartment has been

observed after the arthroscopic treatment of medial *coronoid* disease (8,22). Further details on prevalence and diagnosis of medial compartment erosion are lacking. Therefore, the **first part** of this thesis focused on studying the prevalence and facilitating the diagnosis of medial compartment erosion in the canine elbow. Treatment options for medial compartment erosion have been studied more extensively, yet a generally accepted solution is still lacking. Treatment is challenging since the regenerative capacity of cartilage is limited. As only the medial compartment of the joint demonstrates cartilage damage, specific load-transferring and unicompartmental arthroplasty techniques have been developed (23-25). Because of the irreversible nature of the lesions more attention should be paid to possible preventive measures against the development of medial compartment erosion. Therefore, the **second part** of this thesis focused on reducing the progression of medial *coronoid* disease into medial compartment erosion.

In the **first part of this thesis** the occurrence of the three manifestations of medial compartment erosion is described along with their typical diagnostic features. In our experience, medial compartment erosion was not only diagnosed as a primary or a concomitant condition but was also frequently diagnosed during second-look arthroscopy of elbow joints. Therefore, the first study of this thesis documented the occurrence of medial compartment erosion during second-look arthroscopy in elbows with persistent or recurrent lameness after initial arthroscopic treatment of medial coronoid disease. To our knowledge, this is the first study describing radiographic, computed tomographic and arthroscopic findings in relapsed joints.

It demonstrated that cartilage damage at the second presentation was substantially more extensive in all joints compared to the first arthroscopy. More than half of the joints actually showed medial compartment erosion (modified Outerbridge grade 4-5) during the second-look arthroscopy. Although radiographic and computed tomographic findings indicated moderate to severe osteoarthritis in most of these joints, arthroscopy was indispensable to confirm the diagnosis of medial compartment erosion. Previously, the radiographic progression of degenerative changes after treatment had also been reported in elbow joints with good clinical outcome (9-11). Various theories can be used to explain this progressive degeneration after treatment. Cartilage damage may have been induced by the arthroscopic treatment itself, as removal of a part of the medial coronoid process causes an interruption of the joint surface. It has been suggested that removing a large portion of the medial coronoid process could create deleterious load redistribution within the joint (20). The sustaining

presence of underlying causes of medial coronoid disease such as joint incongruity, not addressed by the arthroscopic treatment, could result in persistent pressure and subsequent cartilage loss of the medial joint compartment (20). However, in our study, radio-ulnar incongruity was observed in less than half of the joints, refuting the latter theory. Loose scar tissue or calcified bodies formed over time, as reported in our study, could potentially irritate the joint causing inflammation and further degeneration. Although not reported in literature, small calcified bodies and/or scar tissue, causing only minimal synovitis, can also be observed in joints with good outcome in the author's experience.

Additional to the diagnosis of cartilage erosion during these second-look arthroscopies, the identification of calcified bodies was an important finding as well. Radiography was an unreliable technique to identify these calcified bodies. Computed tomography on the other hand was always able to identify a calcified body when present. Our findings suggest that the calcified bodies found on second-look arthroscopy developed subsequent to the first intervention. In the past, it had been suggested that the surgeon had overlooked fragment(s) during the initial arthroscopic treatment and thus was erroneously accused of maltreatment. Another theory for the origin of calcified bodies is possible further fragmentation of the medial coronoid process after removal of the earlier fissured/fragmented part. However, when we compared the computed tomography and the arthroscopic images of the first and second presentation of the joints in our study the remaining part of the medial coronoid process after initial treatment still seemed intact at the second presentation. Histopathologic examination of tissue samples taken from calcified bodies in our study demonstrated a degenerative or metaplastic process rather than primary fragments. This finding illustrates some similarities with synovial osteochondromatosis, a benign metaplastic proliferative disorder of the synovium, diagnosed in humans, but also in some cases of dogs and cats (26-29). Whether the calcified bodies found, were the cause of lameness is difficult to conclude from this retrospective study since the amount of joints was limited and concomitant cartilage damage was present in all joints.

Computed tomographic and arthroscopic examination at the second presentation also revealed signs of flexor enthesopathy in some of the joints. It is debatable if flexor enthesopathy was a cause of lameness in the dogs of this study. In 2 joints, we considered the mineralization in the flexor muscles as the cause of lameness since it was the most prominent finding and it was causing pain on palpation. In the other 7 joints with signs of flexor enthesopathy it was uncertain whether lameness was caused by the flexor enthesopathy or by other concomitant

pathologies. In our experience, signs of flexor enthesopathy were also seen in successfully treated elbow joints. Several imaging studies tried to distinguish clinical from subclinical forms of flexor enthesopathy but no differences were found (30-32). The clinical significance could be further clarified in a study comparing the occurrence of signs of flexor enthesopathy in joints with good versus unsatisfactory outcome after arthroscopic treatment of medial *coronoid* disease.

Our study had a few limitations. *First*, the study was limited to a small case series. The number of joints included likely underestimates the prevalence of joints with lameness after arthroscopic treatment of medial *coronoid* disease. Presentation of dogs with lameness after arthroscopic treatment probably depended on several factors: the projected prognosis after the initial treatment, the expectations of the owners, the perception of lameness by the owner, motivation of the owner to return to the University hospital, the judgement and experience of the local veterinarian etc. In addition, 18 joints were excluded from the study because the inclusion criteria were not met. A *second* limitation is the absence of a control series of joints with a good outcome after arthroscopic treatment. However, from an ethical point of view it is difficult to justify a second-look arthroscopic surgery in sound dogs. A *third* limitation is the absence of a computed tomographic examination in some of the joints at the second presentation. Ideally, all joints underwent a computed tomographic examination prior to arthroscopy to ensure detection of all pathologies of the subchondral bone and the articular cartilage. However, computed tomography was skipped in some cases to reduce the costs for the owners.

Given the aforementioned limitations, we could draw the following conclusions. Medial compartment erosion is an important finding in elbows with persistent or recurrent lameness, with or without concomitant scar tissue or a calcified body. The findings in the described 29 joints support the use of both computed tomography and arthroscopy to diagnose the pathologies present in unresponsive joints. The diagnosis of medial compartment erosion in these joints has an impact on treatment decision-making and the expected prognosis. The available results after a second treatment indicate that the prognosis after medical or surgical treatment is guarded. The reason for the development of this full-thickness cartilage damage and how it can be prevented is still undetermined. These findings raise questions on the current treatment approaches for medial *coronoid* disease and encourages further research into novel or modified treatment techniques, such as the last study of this thesis.



The first study of this thesis reported the findings in one type of presentation of medial compartment erosion, but gave no information on its characteristics compared to the other two forms of medial compartment erosion. Therefore, the second study described the arthroscopic findings in three groups of medial compartment erosion in detail. Group 1 consisted of joints with medial compartment erosion as a single finding, in Group 2 medial compartment erosion was diagnosed concomitant with a fragmented/fissured medial coronoid process and/or OCD of the medial part of the humeral condyle and in Group 3 medial compartment erosion was found during second-look arthroscopy in dogs with lameness after arthroscopic treatment of medial *coronoid* disease. Significant differences in age, joint incongruity, extent of the cartilage lesions, damage in the lateral joint compartment and presence of linear abrasion tracks on the medial part of the humeral condyle were found between the three groups.

Overall, the Labrador retriever was the breed most commonly presented with medial compartment erosion. A high prevalence of elbow dysplasia is reported in the Labrador retriever (4) but it remains unclear whether the common presentation with medial compartment erosion is due to the popularity of this breed in Belgium or because of an increased sensitivity for the development of erosion of the medial elbow compartment.

Medial compartment erosion as a concomitant finding (Group 2) was the most common presentation. The least common type was medial compartment erosion as a single finding (Group 1). The fact that dogs in Group 1 were found to be significantly older than dogs in Group 2 and 3 could be expected, considering an earlier description of medial compartment erosion as a single finding in 31% of dogs of six years and older with elbow lameness versus 3 % in ‘young’ dogs (17).

Comparing the arthroscopic pathologies in these three groups of joints with medial compartment erosion resulted in some remarkable findings, especially concerning Group 1. Bearing in mind that a common pathway, including radioulnar incongruity, between medial *coronoid* disease and medial compartment erosion is assumed (2, 16, 33), a first notable observation was that all joints in Group 1 were considered congruent based on the arthroscopic joint inspection. This finding was confirmed on CT-examination in all but one joint. Possible explanations for the development of those severe erosions in joints that appear congruent are misinterpretation of joint incongruity because of the introduction of the arthroscope (34) or the non-weight bearing position of the leg during CT and/or arthroscopy or only temporary presence of incongruity during skeletal growth (2). It is also possible that

the load being placed on the medial compartment of the elbow joint is neither excessive nor abnormal in these cases, but possibly the ability to repair microdamage is abnormal, allowing for accumulation of microdamage. However, this should be a local phenomenon or we would expect to see cartilage damage in other joints of affected animals as well (15).

Complete erosion was most frequently seen in Group 1. Since dogs in Group 1 were significantly older, this finding is consistent with another study reporting a significant relationship between age and the global cartilage pathology found in elbows of Labrador Retrievers with medial *coronoid* disease (35). In our study the extent of the cartilage damage did not seem to correlate with the radiographic degree of osteoarthritis. Even though nearly all joints in Group 1 demonstrated complete erosion of the medial joint compartment, no significant difference was found between the groups in the radiographic degree of osteoarthritis. This finding is contradictory with other studies reporting a relationship between radiographic or CT osteophyte size and the cartilage damage in the medial elbow compartment (35-37). Our findings suggest that radiography might be a useful tool to distinguish elbow joints with (almost) normal cartilage from joints with cartilage erosion, but is not able to estimate the actual extent of the cartilage damage. Therefore, diagnosis of elbow disease solely based on radiographic examination can result in misinterpretation of the severity of the joint pathology.

To the author's knowledge, this is the first study documenting the prevalence of lesions of the lateral joint compartment in joints with medial compartment erosion. In the literature it is stated that pathology of the lateral elbow joint compartment is less common (3). Unexpectedly, this study recognized cartilage damage of the radial head and/or the lateral part of the humeral condyle in 58.3% of the joints with medial compartment erosion. The arthroscopically visible part of the radial head often demonstrated major cartilage damage (modified Outerbridge grade 4-5). Cartilage lesions found on the lateral part of the humeral condyle were minor (modified Outerbridge classification grade 1-3) and a sharp demarcation was still visible with the medial joint compartment. Cartilage damage of the lateral joint compartment was observed in all three groups, but only in Group 1 it was found in all joints. Since in this group no concomitant pathology of the medial coronoid process nor incongruity were diagnosed, it is likely that other factors are involved in the development of cartilage erosion, acting on both the medial and the lateral joint compartment. Since inflammation and degeneration are generalized processes involving the entire joint, it can be questioned whether damage of the lateral joint compartment will not be inevitable in joints with medial

compartment erosion. Therefore detailed inspection of the lateral joint compartment is indispensable before specific treatment methods for medial compartment erosion, such as a unicompartamental elbow arthroplasty or a load-transferring technique, are considered (23, 25). In addition, these treatment techniques developed to treat medial compartment erosion increase or might increase weight bearing forces in the lateral compartment and/or in the region of the anconeal process. Further research on mid- and long-term treatment results of these specific treatment techniques should be conducted to determine the evolution of damage in the lateral compartment and possibly total elbow arthroplasty techniques should be preferred over load-transferring or unicompartamental arthroplasty techniques in the future.

A significant difference between the three groups was also found for the presence of linear abrasion tracks on the medial part of the humeral condyle, but no significant difference was found for the medial coronoid process. Once more, linear abrasion tracks on the medial part of the humeral condyle were most common in Group 1. Overall, linear abrasion tracks were observed in joints with diffuse and complete erosion leading to bone-to-bone contact between the medial coronoid process and the medial part of the humeral condyle. Since all joints in Group 1 demonstrated diffuse/complete erosion, this could explain the high occurrence of linear abrasion tracks.

Erosion of the medial elbow compartment concomitant with a lesion of the medial coronoid process (Group 2) is the most common and best known manifestation of medial compartment erosion. Possibly conflict between the intact portion of the medial coronoid process and the medial part of the humeral condyle caused medial compartment erosion. Another explanation might be that chronic inflammation caused by the presence of a fragment induced the development of erosion of the medial compartment in these cases (2). In the latter case, early treatment of medial coronoid disease would be the key factor to prevent the development of concomitant medial compartment erosion. However, based on the cases included in the first study of this thesis this doesn't suffice to stop the development of medial compartment erosion in some cases.

The prevalence of arthroscopic signs of flexor enthesopathy (29.3%) found in this second study in joints with erosion of the medial compartment is similar to the prevalence during second-look arthroscopy of relapsed joints reported in the first study of this thesis. However, a higher prevalence is found on computed tomographic examination in joints with medial compartment erosion ( 71,4%) and is described in the literature in joints with elbow dysplasia

(72%) (32). A possible explanation for this discrepancy is that subtle changes such as thickening of the flexor muscles were not recognized during arthroscopy because of the presence of severe synovitis in joints with erosion of the medial elbow compartment. Flexor enthesopathy has been described as a primary condition but also concomitant to other elbow pathologies and after treatment of medial *coronoid* disease (30). The occurrence in our studies is therefore not surprising. The reason for the development of enthesopathy after treatment of medial *coronoid* disease is unclear. Possibly trauma during the arthroscopic surgery or chronic inflammation of the joints has induced inflammation or degeneration of the flexor entheses or muscle. Another explanation might be an altered loading of the joint after fragment removal, causing repetitive strain injuries of the flexor muscles. Further research should determine if concomitant flexor enthesopathy occurs more or less often in joints with medial compartment erosion compared to elbows with medial *coronoid* disease without full-thickness cartilage loss.

A *first* limitation of this study is the use of arthroscopy for the evaluation of elbow joint incongruity. Arthroscopy has been described to be an appropriate technique for the diagnosis of radioulnar incongruity (38, 39), but it has been suggested that insertion of the arthroscope and/or the non-weight bearing position of the leg can lead to misinterpretation of joint incongruity (34). The combination of CT-examination and arthroscopic joint inspection is considered ideal to evaluate elbow joint pathology and incongruity (37). In Group 1, CT-examination was included to verify the absence of concomitant pathology of the medial coronoid process. In addition, CT confirmed the congruence of all but one joint in Group 1. CT-examination prior to arthroscopic joint inspection was not a selection criterion in the other two groups to increase the amount of joints included in this study and because the diagnosis of concomitant pathology could be made by arthroscopy as well. A *second* limitation is the use of a new classification scheme. Since the definition of medial compartment erosion is based on the modified Outerbridge classification which only takes into account the depth of the cartilage lesions, an additional classification system to determine the extent of the cartilage lesions in the canine elbow was required. A limitation of this new classification is that it is rather subjective and not quantitative, since our data were collected retrospectively. However, the additional information added by this new classification scheme definitely contributes to the detailed description of the three manifestations of medial compartment erosion. Future use of this new arthroscopic grading system might be beneficial to decide on the type of therapeutic approach used in joints with medial compartment erosion. A *third*

limitation was the limited number of joints included, especially in Group 1. Most likely the prevalence of medial compartment erosion as a single pathology is higher than reported in this study. The requirement of computed tomographic examination prior to the arthroscopic joint inspection to confirm the diagnosis of medial compartment erosion significantly reduced the amount of joints included in Group 1. Since elbow joints with medial compartment erosion have full-thickness cartilage loss, chances are very low that subchondral bone lesions would have been missed during arthroscopy. Therefore the necessity of computed tomography as an inclusion criterion is debatable.

In conclusion, this study provides information on the prevalence and the arthroscopic findings in the three groups of medial compartment erosion and identified several significant differences between the three groups. In particular joints in Group 1, with medial compartment erosion as a single finding, seem to present with different characteristics compared to joints in Group 2 and 3. Possibly other unknown factors are involved in the etiopathogenesis of this type of medial compartment erosion. Furthermore, this study demonstrated several additional pathologies that can occur in joints with medial compartment erosion, such as lesions of the lateral joint compartment, flexor enthesopathy and/or a fragment, a calcified body or loose scar tissue at the level of the medial coronoid process. As mentioned in the first study of this thesis, attention should be paid to diagnose those additional pathologies and they should be taken into account when treatment-decisions are made. Because of the importance of the early detection of cartilage erosion in the canine elbow and their concomitant pathologies and the fact that radiography cannot accurately diagnose them the next study focused on the diagnostic possibilities of CT.

In the third study the computed tomographic findings are described in canine elbows with medial compartment erosion in general and the differences between elbow joints with focal, diffuse and complete erosion. Several computed tomography studies have been performed on canine elbow joints with medial *coronoid* disease, including joints with a variable degree of cartilage damage (20, 37, 40). These studies identified a significant correlation between the largest osteophyte size and the amount of cartilage damage in the medial joint compartment, but a further description of cartilage pathology is not mentioned. To our knowledge, our study is the first to specifically describe computed tomographic findings in joints with medial compartment erosion.

Arthroscopy is considered the gold standard for articular cartilage evaluation, as mentioned above, but lesions of the subchondral bone cannot always be detected (5-7, 37). Computed tomography on the other hand is able to visualize subchondral bone defects, but cannot visualize articular cartilage (13). Given the fact that the joints examined in this study demonstrated full-thickness cartilage loss in the medial elbow compartment it was remarkable that arthroscopy still was not able to visualize some subchondral bone abnormalities that were visible on computed tomographic examination. So, this finding confirms that computed tomography and arthroscopic joint inspection are 'hand in hand' evaluation methods for the detection of elbow lesions in dogs (37) and the combination of this techniques is the most reliable method to diagnose medial compartment erosion and other concomitant pathologies.

Although a significant agreement was found between fragmentation of the medial coronoid process on computed tomography and finding a fragment or calcified body on arthroscopy, in some joints the fragment/calcified body visualized on computed tomography could not be identified during arthroscopy and vice versa. Various theories can explain this discrepancy. Fragments found on arthroscopy were possibly partially cartilaginous and because of their small size overlooked on computed tomographic. On the other hand, fragments visualized on computed tomography that were not identified during arthroscopy were mostly found in joints that underwent second-look arthroscopy. Probably these fragment(s) on computed tomography represented small mineralized areas within scar tissue or were incompletely mineralized osteophytes in the medial coronoid region.

This study of elbows with medial compartment erosion reported a higher prevalence of subchondral bone defects of the medial part of the humeral condyle (96.4%) and lucency of the medial coronoid process (73.2%) compared to the prevalence described in elbows with medial *coronoid* disease (20, 37). In addition, our study was the first computed tomography study paying attention to the lateral elbow compartment as well, since the preceding study on the arthroscopic appearance of elbow joints with medial compartment erosion also identified damage of the lateral part of the humeral condyle and/or the radial head in more than half of the cases. Consequently, this study demonstrated the presence of subchondral bone sclerosis of the radial head and subchondral bone sclerosis and/or a subchondral bone defect of lateral part of the humeral condyle in part of the joints as well. As mentioned above, more attention should be paid to these findings in the lateral compartment and potentially treatment-decision should be altered to a total elbow arthroplasty technique or a conservative/multimodal approach instead of load-transferring or unicompartamental arthroplasty techniques.

The extent of the cartilage loss in the medial elbow compartment can vary from focal to complete erosion, as described in the preceding study. The extent of the erosions has an important influence on treatment options and the prognosis after treatment (8). Therefore, the ability to distinguish these 3 presentations of medial compartment erosion prior to the surgical intervention would significantly facilitate treatment decision-making. Three significant differences were found in this study between joints with focal, diffuse and complete erosion of the medial compartment. However, two of those differences, the presence of fragmentation of the medial coronoid process and the widening of the humeroulnar joint space, are non-specific signs that can also be present in joints with medial *coronoid disease*, without full-thickness cartilage loss (20, 40, 41). The third significant difference, subchondral bone sclerosis of the radial head, was only identified in joints with complete erosion. Therefore this might be a useful indicator for complete erosion of the medial elbow compartment. Further research needs to confirm the accuracy of this parameter. In the future, the application of computed tomography arthrography might potentially add to the pre-surgical diagnosis of focal, diffuse and complete erosion of the medial elbow compartment as well.

It can be concluded that several findings reported in this computed tomographic study contribute to the pre-surgical detection of medial compartment erosion in the canine elbow. Especially when no fragmentation of the medial coronoid process is observed on computed tomography, attention should be paid to computed tomographic signs associated with medial compartment erosion before excluding elbow pathology. Based on the computed tomographic findings a suspected diagnosis of medial compartment erosion can be made. However, arthroscopy is still indispensable to confirm the diagnosis and is still the only method to determine the extent of the erosion which might influence further treatment decision-making. Therefore, this study confirms that the combination of computed tomography and arthroscopy is the most reliable method to diagnose elbow pathology.

Future imaging studies should focus on the use of computed tomography arthrography and/or magnetic resonance arthrography in veterinary medicine in general, and more specifically for the diagnosis of elbow cartilage damage. An important advantage would be that these techniques are less invasive than an arthroscopic surgery, and it would result in an earlier diagnosis of cartilage erosions during the diagnostic process. Currently, the use of computed tomography arthrography has only been described in normal cadaveric canine elbow joints (42). In cadaveric elbows they were able to measure articular cartilage thickness (42). A pilot study was performed at our clinic using computed tomographic arthrography in patients with

elbow dysplasia, but due to several difficulties encountered data were insufficient for publication at the moment and thus further research should be conducted. When high-field MRI-devices become more available in veterinary medicine, the use of MRI and MR arthrography should be further explored as well.

In conclusion, the first part of this thesis illustrated that medial compartment erosion is most commonly observed concomitant to a lesion of the medial coronoid process. Medial compartment erosion is also often reported as a finding during second-look arthroscopy of treated elbows. In those cases medial compartment erosion can be a single finding or -most frequently- concomitant to scar tissue and/or a calcified body at the level of the medial coronoid process. The least common presentation is medial compartment erosion as a single finding. This type of medial compartment erosion seems to present with different characteristics compared to the other two types, indicating a possibly different etiopathogenesis. To diagnose the three different presentations and to determine the extent of the erosion in the medial joint compartment the combination of computed tomographic examination and arthroscopy should be preferred. Although some specific findings in joints with medial compartment erosion were identified both on computed tomography and arthroscopy in this thesis, further research should focus on directly comparing findings in joints with full-thickness cartilage erosion versus partial thickness or no cartilage erosion and comparing joints with an unsatisfactory outcome after treatment versus joints with a good outcome. This might facilitate diagnosis and treatment decision-making in joints with medial compartment erosion and additionally contribute to unraveling the reason for the development of this severe cartilage damage in these three specific circumstances, which is still unclear at the moment.

From the first part of this thesis we learned that an important number of joints affected by medial compartment erosion underwent a previous arthroscopic treatment. It is commonly known that a routinely performed arthroscopic treatment of medial *coronoid* disease results in a good clinical outcome in the short- and medium-term, but in the long-term lameness and progression of degenerative changes occur (9, 11). Even in cases with a discrete lesion such as a fissure of the medial coronoid process in the absence of secondary cartilage lesions, treatment might lead to lameness and osteoarthritis in the long term as described in the first study of this thesis. The reason for this negative evolution is not fully understood, but one of the suggested causes is an overload of the medial compartment before and/or after treatment. We hypothesized that a changed load distribution might prevent or diminish the postoperative



degeneration of the joint. We also hypothesized that an ulnar osteotomy would unload the medial coronoid process and thus eliminate the pain originating from the subchondral fissure. Therefore a modified treatment approach of medial *coronoid* disease in immature dogs is described in the **second part of this thesis**. More specifically a bi-oblique dynamic proximal ulnar osteotomy as a single treatment i.e. without concurrent arthroscopic debridement of the medial coronoid lesion, was investigated in joints affected by a fissure of the medial coronoid process.

The bi-oblique proximal ulnar osteotomy was selected as a treatment technique in favor of other surgical procedures since this is a routinely performed technique, for example to treat elbow joints with an ununited anconeal process (43). Thereby surgeons were already familiar with the procedure and the known complication rate was low. In addition, a proximal ulnar osteotomy creates a 3D-movement of the proximal ulnar segment and thereby permits dynamic unloading or redistribution of forces along the contact area of the medial coronoid process (44, 45). The position of the osteotomy was aimed at the junction of the proximal and mid-third of the ulna, above the interosseous ligament, to permit sufficient movement of the proximal ulnar segment (46). In our study the ulnar osteotomy was located at on average 36% of the total ulnar length. This was similar to the position of the osteotomy at on average 39% of the total ulnar length in the study of Caron and Fitzpatrick (2016) (47).

The osteotomy was performed in an oblique direction to prevent extreme tilting of the proximal segment and no further internal stabilization of the ulna is necessary (46-48). At the moment the ideal ulnar osteotomy angulation is unknown. In our study, the osteotomy was directed from distomedial to proximolateral and craniodistal to caudoproximal in an angle of approximately 40° in both directions. The mean angles reported in literature are 55° for the caudo-cranial angle and 48° for the latero-medial osteotomy angle, with a 13% coefficient of variation (47, 48). It is stated that a more acute angulation of the osteotomy might increase chances of excessive migration of the proximal ulnar segment (47). This abnormal excessive migration is defined as extreme movement of the proximal ulnar segment causing deleterious motion of the ulnar articular surface (47). However, there is no exact description of which amount of displacement is considered abnormal/excessive. Displacement of the proximal ulnar segment reported in our study varies from 3.3° to 17.7° in the caudal direction and from 5.38° to 19.1° in the lateral direction and never seemed extraordinary. In the 4 dogs that underwent second-look arthroscopy no abnormal displacement of the ulnar articular surface was observed during inspection of the elbow joint.

In 4 out of 8 dogs (= Group 1) in our study lameness resolved after treatment with a bi-oblique dynamic proximal ulnar osteotomy. In addition, the elbow of one of these dogs remained free of osteophytes on radiography 4 years postoperatively. On the other hand, lameness persisted or recurred in the other 4 dogs (= Group 2) and a second surgery was required to arthroscopically remove the fissured part of the medial coronoid process. A success of only 50% is quite disappointing and is in contrast with the findings of another study that reported an improvement in lameness score in all cases with developmental elbow disease after treatment with a bi-oblique dynamic proximal ulnar osteotomy (47). In the latter study, a bi-oblique dynamic proximal ulnar osteotomy was not only performed in dogs with a lesion of the medial coronoid process but also in cases with an united anconeal process and/or elbow incongruity. Nevertheless, both studies demonstrate that a bi-oblique dynamic proximal ulnar osteotomy offers the ability to resolve lameness in certain cases. However, appropriate patient selection is probably crucial and further research should focus on this.

The radiographic amount of periarticular osteophytosis increased in all but one elbow. This increase was mainly observed at the first long-term follow-up visit (in general 1 year postoperatively). During the following long-term follow-up evaluations the amount and size of the osteophytes remained alike. The arthroscopic debridement performed during a second-look arthroscopy in half of the joints might have influenced this progression of osteoarthritis. A remarkable finding was that the largest osteophyte developed on the cranial aspect of the radial head, while osteophytes at other locations in the joint were often less prominent. The osteophyte at the radial head is probably the main reason for the decreased range-of-motion observed at long-term follow-up and was also the cause of a higher degree of osteoarthritis in several joints. If the size of the radial osteophyte was omitted the general osteoarthritis score would be significantly lower with only one joint demonstrating grade 2 osteoarthritis, and all other joints showing degree 0 or 1 at the long-term follow-up radiographs.

Arthroscopic debridement of the lesion of the medial coronoid process was necessary to resolve lameness in half of the dogs. Despite the postponement of the arthroscopic treatment, nearly no progression in articular cartilage damage was observed during this second-look arthroscopy. So it seems that, although based on a small number of cases, an ulnar osteotomy as a single treatment may be performed without the risk of a negative outcome when an arthroscopic debridement has to be carried out after all. The only downside is the increased morbidity (i.e. prolonged period of lameness) after an ulnar osteotomy and the need for a second anesthesia/surgery in part of the cases.

Although an association between the degree of osteoarthritis and the amount of articular cartilage damage has been demonstrated (3, 17, 35), a second-look (or third-look) arthroscopy would be necessary to definitively evaluate progression of cartilage damage in the long-term and to confirm slower progression of degenerative cartilage changes in the medial elbow compartment after treatment with a bi-oblique dynamic proximal ulnar osteotomy.

A larger displacement of the proximal ulnar segment in both caudal and lateral direction was found in the elbow joints that needed an additional arthroscopic debridement. One would have expected that this larger displacement resulted in a more pronounced unloading of the fissured medial coronoid process and thereby should have resolved lameness in these cases. Possibly the rotational movement of the proximal ulnar segment, that cannot be measured on radiography, resulted in an increased friction between radius and ulna leading to the need for debridement of the fissured part of the coronoid process. Nevertheless, no problems with bone healing occurred in these joints and the second-look arthroscopy did not illustrate abnormal displacement of the ulnar articular surface. Anyhow, this finding supports the theory that a more extreme movement of the proximal ulnar segment is less advantageous.

Despite the young age of the dogs and the bi-oblique direction of the ulnar osteotomy a non- and delayed union were observed. Delayed healing of the ulnar osteotomy site was reported in another study as well, that could not identify a significantly different angulation or height for complicated and uncomplicated elbows (47). Fixation of the ulnar osteotomy with an intramedullary pin has been abandoned with the introduction of a bi-oblique dynamic osteotomy (49, 50). Pin placement probably reduced problems with bone healing but was associated with increased morbidity (e.g. pin breakage) (14). Recently, another ulnar osteotomy technique, the proximal abduction ulnar osteotomy (PAUL), has been described fixing the ulnar osteotomy with a stepped plate (51). This plate probably ensures bone healing as well. Preliminary outcome results of the PAUL technique combined with treatment of the medial coronoid lesion seem promising (51). However, the PAUL technique creates a medial displacement of the proximal ulnar segment, which is opposite compared to the movement after a bi-oblique dynamic proximal ulnar osteotomy and therefore more data on long-term results are required to determine the value of this new technique and the effect of this altered load distribution.

Findings in this study should be interpreted with care because of the small number of included dogs. A second limitation is the subjective evaluation of lameness. We tried to limit the

subjectivity of this evaluation by using three independent observers randomly evaluating the video sequences. Ideally, objective pressure plate follow-up was performed. A third limitation concerns the measurement of the displacement of the proximal ulnar segment. Although it has been described that the proximal ulnar segment makes a complex 3D-movement after a bi-oblique dynamic proximal ulnar osteotomy, we were only able to measure 2D-displacement based on the radiographs. Nevertheless, these 2D measurements included the caudal tipping, which is assumed to be the main movement of the proximal ulnar segment (52).

It can be concluded that a bi-oblique dynamic proximal ulnar osteotomy can be performed as a single treatment method in immature dogs diagnosed with a fissured medial coronoid process. Nevertheless, lameness persisted or recurred in half of the joints and thereby a second arthroscopic surgery was required to remove the fissured part of the medial coronoid process. Overall, a satisfying outcome was reached in all joints. This promising outcome warrants further investigation of this novel treatment approach for management of a fissure of the medial coronoid process in immature dogs. Further research should also focus on the modification of the treatment approach of cases with a displaced fragment, for example the combination of arthroscopic debridement of the fragment and a bi-oblique dynamic proximal ulnar osteotomy to address radioulnar incongruity as well.

The main conclusion of this thesis is that the diagnosis of medial compartment erosion of the canine elbow joint via non-invasive imaging techniques remains challenging and arthroscopy is indispensable to confirm the diagnosis and estimate the extent of the cartilage damage. In the future, non-invasive visualization of articular cartilage in canine elbows should be further investigated, e.g. computed tomography arthrography. Several joint pathologies can be found concomitant with erosion of the medial compartment and should be all taken into account when treatment-decisions are made. However, since cartilage regeneration is limited, further research should focus on the early diagnosis of (limited) cartilage erosion in the medial elbow compartment as well as on prevention of the development of medial compartment erosion by modifying current treatment approaches.

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## **SUMMARY**



## **SUMMARY**

Medial compartment erosion, referring to full-thickness cartilage loss with exposure of the subchondral bone (modified Outerbridge grade 4-5) of the medial part of the humeral condyle and the corresponding ulnar contact area, is reported in three situations: As a single pathology, as a concomitant finding with medial coronoid pathology and/or osteochondritis dissecans of the medial part of the humeral condyle, or as a finding during second-look arthroscopy in dogs with persistent or recurrent lameness after initial arthroscopic treatment of medial coronoid disease.

Originally the term ‘medial compartment disease’ was used to describe full-thickness cartilage loss in the medial part of the canine elbow. However, the term ‘medial *compartment* disease’ is often confused with the term ‘medial *coronoid* disease’, indicating fissuring or fragmentation of the medial coronoid process with or without severe cartilage damage. Therefore the more descriptive term ‘medial compartment erosion’ was introduced, to avoid confusion and to set out a better specification of the pathology within the joint.

In **section I** an overview is given of the current knowledge about occurrence, diagnosis and treatment options for erosion of the medial elbow compartment. Imaging articular cartilage lesions by means of radiography, ultrasonography, computed tomography or magnetic resonance imaging is challenging in dogs. Arthroscopy enables direct visualization of the articular joint surface and is therefore the gold standard for the evaluation of articular cartilage. Several conservative and surgical treatment methods have been proposed to treat elbows with severe cartilage defects. However, due to the limited regenerative capacity of cartilage and the invasive character of some procedures, the prognosis in these cases is guarded.

In **section II** the scientific aims of this PhD thesis are described. The general aim is to gain more information about the prevalence, diagnostic aspects and preventive measures of medial compartment erosion, in order to facilitate diagnosis and treatment-decision making. Medial compartment erosion is considered to be an advanced stage of medial coronoid disease. However, the presence of this full-thickness cartilage loss has severe consequences for the prognosis after treatment of these joints. The first aim is to report on the findings in dogs with lameness after arthroscopic treatment of medial coronoid disease. The second aim is to describe the prevalence of the three manifestations of medial compartment erosion and report on the concomitant arthroscopic findings in these joints. The third aim is to describe the

computed tomographic findings in elbow joints with erosion of the medial compartment. The fourth and last aim is to evaluate the outcome after treatment of medial coronoid disease by an ulnar osteotomy without additional arthroscopic treatment, in skeletally immature dogs.

In **chapter 1** of section III the arthroscopic, computed tomographic and radiographic findings in dogs with lameness after arthroscopic treatment of medial coronoid disease are discussed. The medical records (2005-2009) of dogs with elbow lameness after arthroscopic removal of a fissured/fragmented medial coronoid process were reviewed retrospectively. Only dogs with complete medical records, including radiographs, computed tomographic and arthroscopic images, from the first and second presentation were included. Twenty-nine joints (25 dogs) met the inclusion criteria. At the second presentation, on average 2.7 years later, a radiographic increase in osteoarthritis was noticed in all 29 joints. Findings near the medial coronoid process based on computed tomography and second-look arthroscopy were: A calcified body in 11 joints, multiple calcified bodies in 1 joint, loose scar tissue in 12 joints and immobile scar tissue in 2 joints. In 15 joints medial compartment erosion was diagnosed concomitant with the coronoid pathology. In 3 joints there was no calcified body or scar tissue found and erosion of the medial compartment was the only pathology diagnosed in the coronoid region. Characteristics of flexor enthesopathy were identified on computed tomography and/or arthroscopy in 9 joints as well. Treatment performed during second-look arthroscopy consisted of the removal of tissue that seemed to disturb joint function. Follow-up in 22/29 joints after second-look arthroscopy indicated an improvement of lameness in 59% ( $n = 13$ ) of the joints. In conclusion, when dealing with relapsed joints one should not only focus on the increased degenerative changes, but also on additional lesions like a calcified body or loose scar tissue in the medial joint compartment as a possible cause of lameness.

**Chapter 2** reports on the prevalence of the three manifestations of medial compartment erosion and the arthroscopic findings in these joints. Retrospectively, records of 84 elbow joints from 66 dogs diagnosed arthroscopically with erosion of the medial compartment were retrieved from a medical records database (2008 - 2012). In 9 joints (10.7%) full-thickness cartilage erosion was the only pathological finding (= Group 1). Group 2 ( $n = 50$ , 59.5%) consisted of elbows with medial compartment erosion concomitant with medial coronoid process pathology. In this group, a displaced fragment of the medial coronoid process was the predominant concomitant finding. In group 3 ( $n = 25$ , 29.8%), erosion of the medial elbow compartment was diagnosed during a second-look arthroscopy in dogs presented with lameness after arthroscopic treatment of medial coronoid disease. There was a significant age

difference between the groups, with the dogs of group 1 being the oldest. Complete erosion of the medial compartment was most commonly found in group 1, whereas focal cartilage erosion was mostly identified in group 2. Overall, additional cartilage pathology of the lateral part of the humeral condyle and/or the radial head was recognized in 58.3% of the joints. These findings may contribute to the search for the ethiopathology and treatment strategy of medial compartment erosion.

**Chapter 3** provides an overview of the computed tomographic findings in elbow joints diagnosed with erosion of the medial compartment. The identification of specific computed tomographic findings might facilitate the non-surgical diagnosis and add to treatment decision-making. In this retrospective study computed tomographic images of 56 elbows, arthroscopically diagnosed with medial compartment erosion, were evaluated and compared in elbows with focal ( $n = 13$ ), diffuse ( $n = 11$ ) and complete ( $n = 32$ ) erosion. The most prevalent CT signs were periarticular osteophytosis (100%), an abnormal shape of the medial coronoid process (96.4%) and a subchondral bone defect of the medial part of the humeral condyle (96.4%). The 3 groups differed significantly in terms of presence of fragmentation of the medial coronoid process, radial head subchondral bone sclerosis and widening of the humeroulnar joint space. When comparing computed tomographic and arthroscopy, no significant agreement was found between the observation of a subchondral bone defect of the medial part of the humeral condyle on computed tomography versus arthroscopy. A significant agreement was found between computed tomography and arthroscopy for the detection of fragmentation of the medial coronoid process. However, some of the calcified body/fragment(s) visualized on computed tomography in the region of the medial coronoid process could not be identified via arthroscopy. Distinguishing focal, diffuse and complete erosion on computed tomographic examination remains difficult, despite the identification of 3 significantly different findings. An accurate estimation of the extent of the cartilage lesions still requires arthroscopic joint inspection.

In **chapter 4** a bi-oblique dynamic proximal ulnar osteotomy is assessed as a single treatment for fissuring of the medial coronoid process in skeletally immature dogs. Eight dogs diagnosed with a fissured medial coronoid process were included and preoperative clinical and radiographic findings were compared to the findings in the long-term. Short-term follow-up demonstrated that lameness resolved after treatment with an ulnar osteotomy in half of the dogs. Lameness persisted or recurred in the other half, requiring arthroscopic removal of the fissured part of the medial coronoid process. Long-term follow-up revealed an excellent or

good outcome in all but one dog, based on owner assessment. An increase in periarticular osteophytosis was found in all but one joint. In conclusion, this small case series indicates that a bi-oblique dynamic ulnar osteotomy has the ability to resolve lameness, but in some cases a second arthroscopy is still required to remove the fissured part of the medial coronoid process.

**Section IV** comprises the general discussion and conclusions. Imaging techniques such as radiography and computed tomography can contribute to the presumptive diagnosis of medial compartment erosion and concomitant elbow pathologies. However, arthroscopic inspection of the elbow joint is still indispensable to confirm the diagnosis of medial compartment erosion and determine the extent of the cartilage damage. Based on the arthroscopic findings treatment decision can be made. Nevertheless, future studies should focus on novel treatment approaches for medial *coronoid* disease, such as a bi-oblique dynamic proximal ulnar osteotomy, to reduce the progression of joint degeneration after treatment.



## **SAMENVATTING**



## **SAMENVATTING**

Oorspronkelijk werd de term ‘medial *compartment* disease’ gebruikt om te verwijzen naar uitgebreide kraakbeenerosies in het mediale gedeelte van het ellebooggewricht bij de hond. Deze term werd regelmatig verward met de term ‘medial *coronoid* disease’, waarmee een fissuur of een fragment van de mediale processus coronoideus bedoeld wordt al dan niet in combinatie met erge kraakbeenschade. Daarom werd de meer beschrijvende term erosie van het mediale elleboogcompartiment voorgesteld om verdere verwarring te vermijden en een betere specificatie te geven van de afwijking in het gewricht.

In **sectie I** wordt een overzicht gegeven van de huidige kennis over het voorkomen, de diagnose en de behandelingsopties voor erosie van het mediale elleboogcompartiment bij de hond. Deze aandoening houdt in dat het kraakbeen over zijn volledige dikte is aangetast (Outerbridge graad 4-5) met blootstelling van het subchondraal bot van het mediale deel van de humeruscondyl en het tegenoverliggende contactgebied van de ulna. Deze erosies van het mediale compartiment worden gerapporteerd in 3 omstandigheden: als een alleenstaande aandoening, samen met een letsel van de mediale processus coronoideus en/of osteochondrosis dissecans van het mediale deel van de humeruscondyl, of als een bevinding tijdens een tweede arthroscopische ingreep bij honden met manken na de initiële behandeling van een letsel van de mediale processus coronoideus. In beeld brengen van gewrichtskraakbeen via radiografie, echografie, computer tomografie of nucleaire magnetische resonantie is moeilijk bij de hond. Arthroscopie is de gouden standaard voor de evaluatie van gewrichtskraakbeen. Verschillende conservatieve en chirurgische behandelingen zijn reeds ontwikkeld om ellebogen met erge kraakbeenletsels te behandelen. De prognose blijft echter gereserveerd omwille van de beperkte regeneratieve capaciteit van kraakbeen en het invasieve karakter van sommige chirurgische ingrepen.

In **sectie II** worden de wetenschappelijke doelstellingen van dit doctoraatsonderzoek beschreven. De algemene doelstelling is om meer informatie te verkrijgen over de prevalentie en diagnostiek van erosie van het mediale elleboogcompartiment en mogelijke preventieve ingrepen die kunnen uitgevoerd worden. Mogelijks kan hierdoor het diagnostisch proces en de keuze van de behandeling in de toekomst vergemakkelijkt worden. Erosies van het mediale elleboogcompartiment worden beschouwd als een vergevorderde vorm van ‘medial *coronoid* disease’. De aanwezigheid van deze uitgebreide kraakbeenerosies hebben echter ernstige gevolgen voor de prognose na behandeling van deze gewrichten. De eerste doelstelling is om

de diagnostische bevindingen bij honden met mankheid na de artroscopische behandeling van een letsel van de mediale processus coronoideus te beschrijven. De tweede doelstelling is dan om de prevalentie van de drie vormen van erosies van het mediale compartiment te bepalen en de concomitante letsel te beschrijven die gevonden worden tijdens artroscopie. De derde doelstelling is om de computer tomografische bevindingen in ellebooggewrichten met erosies van het mediaal compartiment te omschrijven. De vierde en laatste doelstelling is om het klinisch resultaat en de ontwikkeling van osteoarthritis te evalueren na de behandeling van een fissuur van de mediale processus coronoideus bij juveniele honden via een osteotomie van de ulna,.

In **hoofdstuk 1** van sectie III worden de artroscopische, computer tomografische en radiografische bevindingen besproken bij honden met mankheid na de artroscopische behandeling van ‘medial coronoid disease’. De medische gegevens (2005-2009) van honden met persisterend of recidiverend manken na de artroscopische behandeling van een fissuur/fragment van de mediale processus coronoideus werden retrospectief verzameld. Enkel honden met een volledig medisch dossier, inclusief radiografieën, computer tomografische en artroscopische beelden van de eerste en tweede presentatie werden geïncludeerd. Negenentwintig gewrichten (25 honden) voldeden aan deze voorwaarden. Bij de tweede presentatie, gemiddeld 2.7 jaar later, toonde radiografisch onderzoek een toename van osteoarthritis in alle 29 gewrichten. Bevindingen, gebaseerd op computer tomografie en artroscopie, bij de tweede presentatie in de regio van de medial processus coronoideus waren: een calcificatie in 11 gewrichten, multiële calcificaties in 1 gewricht, los littekenweefsel in 12 gewrichten en immobiel littekenweefsel in 2 gewrichten. In 3 gewrichten werd er geen calcificatie of los littekenweefsel gevonden en was erosie van het mediale gewrichtscompartiment de enige pathologie aanwezig in de regio van de medial processus coronoideus. In 15 gewrichten werd erosie van het mediale compartiment eveneens gediagnosticeerd in combinatie met de hierboven beschreven letsels in de regio van de mediale processus coronoideus. Via computer tomografie en artroscopie werden eveneens tekenen van flexor enthesopathie gediagnosticeerd in 9 gewrichten. Er kan geconcludeerd worden dat bij het behandelen en diagnosticeren van hervallen ellebooggewrichten men niet alleen moet focussen op de degeneratieve veranderingen in het gewricht maar ook moet letten op de aanwezigheid van bijkomende letsels zoals een calcificatie of los littekenweefsel in het mediale gewrichtscompartiment.

In **hoofdstuk 2** wordt de prevalentie van de drie vormen van erosie van het mediale compartiment en de artroskopische bevindingen in deze gewrichten in detail bekeken. Retrospectief werden de medische gegevens geanalyseerd van 84 ellebogen van 66 honden die artroschopisch gediagnosticeerd werden met uitgebreide kraakbeenschade van het mediale compartiment. In 9 gewrichten was uitgebreide kraakbeenschade een alleenstaande aandoening (= Groep 1). Groep 2 (n= 50, 59.5%) bestond uit ellebogen met kraakbeenerosies samengaan met een letsel van de mediale processus coronoideus. In deze groep was een verplaatst fragment van de mediale processus coronoideus de meest voorkomende concomitante bevinding. In Groep 3 (n= 25, 29.8%) werden erosies van het mediale compartiment gediagnosticeerd tijdens een tweede artroskopische ingreep bij honden met manken na een initiële behandeling van een letsel van de mediale processus coronoideus. Er werd een significant leeftijdsverschil vastgesteld tussen de groepen, waarbij de honden in Groep 1 het oudst waren. Complete erosie van het mediale compartiment werd meest gevonden in Groep 1, terwijl focale erosies meest gezien werden in Groep 2. Algemeen werden bijkomende kraakbeenletsels van het laterale deel van de humeruscondyl en/of de radiuskop gevonden in 57.6% van de gewrichten. De bevindingen van deze studie kunnen bijdragen tot de zoektocht naar de etiopathologie van erosies van het mediale elleboogcompartiment en de gepaste behandelingsmogelijkheden.

**Hoofdstuk 3** geeft een overzicht van de computer tomografische bevindingen in ellebogen met erosies van het mediale compartiment. De bevindingen in deze studie kunnen de niet-chirurgische diagnose van erosies van het mediale elleboogcompartiment mogelijks vereenvoudigen in de toekomst en daarbij ook bijdragen aan de behandelingskeuze. In deze retrospectieve studie werden de computer tomografische beelden van 56 ellebogen, artroschopisch gediagnosticeerd met erosie van het mediale compartiment, geëvalueerd en vergeleken tussen ellebogen met focale (n = 13), diffuse (n = 11) en complete (n = 32) erosie van het mediale compartiment. De meest voorkomende bevindingen waren periarticulaire osteofytose (100%), een abnormale vorm van de mediale processus coronoideus (96.4%) en een subchondraal defect van het mediale deel van de humeruscondyl (96.4). De 3 groepen verschilden significant op vlak van aanwezigheid van fragmentatie van de mediale processus coronoideus, subchondrale sclerose van de radiuskop en verwijding van de humeroulnaire gewrichtsruimte. Bij het vergelijken van de computer tomografische en artroskopische bevindingen was er echter geen significante overeenkomst tussen de observatie van een subchondraal defect van het mediale deel van de humeruscondyl via computer tomografie

versus artroscoopie. Er werd wel een significante overeenkomst gevonden tussen computer tomografie en artroscoopie voor de detectie van een fragment ter hoogte van de mediale processus coronoideus. Nochtans konden sommige calcificaties/fragmenten die gevonden werden via computer tomografie niet geïdentificeerd worden via artroscoopie. Ondanks dat er 3 significante verschillen tussen de groepen werden gevonden, blijft het moeilijk om via computer tomografie een onderscheid te maken tussen focale, diffuse of complete erosie van het mediale elleboogcompartiment. De exacte bepaling van de uitgebreidheid van de erosies vereist nog steeds artroscopische inspectie van het gewricht.

In **hoofdstuk 4** wordt een bi-oblique dynamische proximale osteotomie van de ulna beoordeeld als een behandeling voor een fissuur van de mediale processus coronoideus bij juveniele honden. In deze prospectieve studie werden 8 honden geïncludeerd die 1 tot 4 jaar werden opgevolgd. Opvolging op korte termijn toonde aan dat de mankheid verdween bij de helft van de honden na behandeling met een osteotomie van de ulna. In de andere helft van de honden persisteerde of recideerde het manken en was een artroscopische ingreep noodzakelijk om de fissuur van de medial processus coronoideus te verwijderen. Opvolging op lange termijn demonstreerde een uitstekend of goed klinisch resultaat, gebaseerd op evaluatie van de tevredenheid van de eigenaar, in alle honden uitgezonderd één. Een toename in radiografische osteofytose werd vastgesteld in alle gewrichten uitgezonderd één. Er kan geconcludeerd worden dat deze studie aantoont dat een bi-oblique dynamische proximale osteotomie van de ulna manken kan verhelpen. In sommige gevallen is er echter een bijkomende artroscopische ingreep noodzakelijk om de fissuur van de mediale processus coronoideus alsnog te verwijderen.

**Sectie IV** omvat de algemene discussie en conclusies van dit doctoraat. Beeldvormingstechnieken zoals radiografie en computer tomografie kunnen helpen bij het stellen van een vermoedelijk diagnose van erosie van het mediale elleboogcompartiment en andere bijkomende letsels. Artroscoopie is echter nog steeds noodzakelijk om de diagnose te bevestigen en de uitgebreidheid van de kraakbeenletsels in te schatten. Aan de hand van de artroscopische bevindingen kan een behandelingsplan opgesteld worden. Desondanks dient verder onderzoek gefocust te worden op nieuwe behandelingsmethodes voor letsels van de mediale processus coronoideus, die de progressie van kraakbeenletsels na behandeling reduceren.

# **CURRICULUM VITAE**





## **CURRICULUM VITAE**

Eva Coppieters werd geboren op 1 februari 1987 te Lokeren. Na het behalen van het diploma hoger secundair onderwijs, richting Latijn-Wiskunde aan het Sint-Lodewijkscollege te Lokeren, startte zij in 2004 met de studies Diergeneeskunde aan de Universiteit Gent. In 2010 behaalde zij het diploma van Master in de diergeneeskunde (afstudeerrichting gezelschapsdieren) met grote onderscheiding.

Aansluitend startte ze een internship bij de dienst orthopedie van de vakgroep Medische Beeldvorming van de huisdieren en Orthopedie van de kleine huisdieren. Tijdens dit internship raakte zij geboeid door de orthopedie en ontstond haar interesse in wetenschappelijk onderzoek. Na een succesvolle aanvraag van een doctoraatsbeurs bij het IWT (agentschap voor innovatie door wetenschap en technologie) startte zij haar doctoraat in januari 2012 onder begeleiding van Prof. Van Ryssen.

Eva Coppieters is auteur en medeauteur van verschillende wetenschappelijke publicaties in internationale tijdschriften en nam deel aan verschillende nationale en internationale congressen.



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## **DANKWOORD**



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